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EVALUATION OF SMALL MODULAR INCINERATORS IN MUNICIPAL PLANTS

Ross Hofmann Associates
Coral Gables, Florida

1976

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EVALUATION OF SMALL MODULAR INCINERATORS IN MUNICIPAL PLANTS

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This report describes in detail the results of monitoring three small municipal incinerators, including one that incorporates steam recovery. The three incinerators tested were all under 50 TPD design capacity per furnace and were burning typical municipal solid waste. Cost information was accumulated for each facility and, where applicable, revenue from steam sales was included. Operational, performance, and environmental analyses were performed for all units involved. This report is the latest state-of-the-art report on small incineration, should serve as a guide for municipalities considering such a system, and can be used for comparison purposes in future solid waste system evaluations.

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A great many people contributed to the effort involved in producing this report. To our knowledge, this is the first detailed study on the use of small modular incinerator plants, owned and operated by municipalities. The help furnished the contractor, by so many people outside his organization, considerably expedited the completion of the effort and solved many of the problems that arose as the study progressed.

We would like to express our appreciation to the elected and appointed officials of the municipalities in which each of the incineration plants were located. They gave freely of their time and facilities; they supplied the study and monitoring teams with much needed equipment and other resources; they kindly accepted the inconveniences of large monitoring teams at their plants; and provided complete access to all their records concerned with the purchase and operation of the equipment and plants and their overall solid waste management system.

The personnel of the Office of Solid Waste Management, U. S. Environmental Protection Agency were invaluable in the assistance they rendered to the study. From their experience with municipal solid waste management, and with incinerator monitoring, they continually contributed to the solving of various problems that arose and to decisions that had to be reached for determining optimum monitoring methods that could be used. We are particularly grateful to Steven J. Hitte and Allen Geswein for the help they rendered at each test site and in the numerous conferences that led to the final format of this report.

Finally, we wish to express our appreciation to the management and engineering personnel of Consumat Systems and two of their distributors, Florida Gas Company and U. S. Recycle Corporation, who designed and constructed the plants that were studied.

To all these groups we state that, if this study proves to be of benefit to the municipalities who are anxious to obtain details on the advantages and problems in incinerating municipal wastes and of waste heat recovery systems for steam production, much of the credit for presenting the facts contained in this report belongs to our many associates in the endeavor.

Ross Hofmann, Associates
Coral Gables, Florida

SUMMARY OF FINDINGS

1. The incinerators studied in this report have individual waste burning capacities of less than 50 tons per day and hence are rated as "small" incinerators. They are installed in municipal incinerator plants in identical modules of two to eight units to achieve the desired plant capacity. Normal variations in municipal waste can be processed in the incinerators without special treatment (such as shredding) before charging.

2. They utilize a controlled air principle. Municipal waste is burned "as received" in a primary combustion chamber in a reducing atmosphere, of insufficient oxygen for complete combustion, to minimize particulates in the gas stream. The effluent gas is then burned in a secondary chamber, utilizing an oxidizing or excess air atmosphere to burn the entrained particulates. Auxiliary fuel (gas or oil) is used to assist the combustion process.

3. The incinerators operate on a batch feed basis, rather than continuously, within a 24 hour cycle; normally being charged for seven to eight hours; then burning down with the use of auxiliary fuel for approximately three more hours; allowed to cool overnight; with the ash residue removed by an operator each morning, before the start of the next 24 hour cycle.

4. Due to combustion design, and without mechanical or water-operated pollution control devices, the gases expelled by the incinerators into the atmosphere have very low particulate readings. Stack emissions from the tested incinerators ranged from 0.03 to 0.08 grains of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent CO_2.

5. The efficiency of thermal processing was excellent and compared favorably with the largest municipal incinerators. Weight reduction of the raw waste averaged 68% and volume reduction averaged 93%. Laboratory testing of the incoming waste and the residue revealed excellent burning rates.

6. One plant used #2 oil as auxiliary fuel; the others used natural gas. Natural gas consumption per ton of waste burned averaged from 440 $ft.^3$ to 1239 $ft.^3$. Oil consumption per ton of waste burned averaged 18 gallons.

7. The models tested were of different capacities. The largest burned waste consistently at a rate of 12.5 tons per 24 hour cycle which was equal to its design capacity. A second unit averaged during the testing period a

burning rate of 7 tons per 24 hours, and during the test days was used from 51 to 80% of design capacity. The third unit averaged 5.8 tons per 24 hours, and during test days was used from 58 to 89% of design capacity.

8. The characteristics of the municipal waste at the studied plants were analyzed. Densities varied from plant to plant and sample to sample. Plant averages varied from 7.9 to 10.9 to 11.5 lbs./ft^3 during testing. Individual large samples (up to 1400 pounds in weight) varied from 4.6 to 24.4 lbs./ft^3. Separation studies showed wide variations in the combustible and non-combustible fractions of the "as received" waste streams. Laboratory analyses showed variations in moisture from 20.8% to 49.9%, and variations in heat content on an "as received" basis from 2408 Btu/lb. to 4353 Btu/lb; and ranges from 6596 Btu/lb to 8720 Btu/lb in the dried combustible component.

9. A waste heat recovery system produced steam from the effluent incinerator gases as they passed through a companion boiler. During testing 47,425 pounds of steam at 100 psig were produced from burning 8.3 tons of waste with an average value of 4353 Btu/lb. This gave a boiler efficiency of 72.8%.

10. Capital costs per ton of design capacity for all buildings, site improvements and incinerators, completely installed, were from $9,093 to $9,494 for straight incinerator plants. With energy recovery (steam production), these rose to $17,667 per ton of design capacity. With interest applied, capital costs account for from $3.57 to $4.46 per ton of waste processed in the straight incinerator plants, and up to $7.31 per ton processed in the steam production plant.

11. Operating costs of the incinerators on a "per ton processed" basis varied considerably. With the straight incineration plants, the range was from $6.26 to $15.69. The gross cost in the steam production plant was $8.75; however, minimum steam sales revenue reduced this to a net of $2.68 per ton processed. Labor in two of the plants was the largest operating cost element, ranging from $3.98 to $5.74 per ton processed. Auxiliary fuel was the largest cost in the plant using #2 oil and ran $8.17 per ton of waste processed. Where gas was used, the fuel cost per ton of waste processed was from $0.82 to $1.24. Water was a major cost when steam was produced.

12. Total annual costs, combining operating and capital-ownership cost elements, compared favorably with large scale plants, ranging from $8.50 to $18.53 per ton processed (without interest on investment) for straight incineration, to a net of $9.99 per ton (including interest on investment) for the steam production plant after deducting steam sales revenue.

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CHAPTER 1

INTRODUCTION

Objectives and Scope of the Study

In March 1975, under EPA Contract 68-01-3171, Ross Hofmann Associates commenced a nine month investigation into the environmental aspects, operating parameters, and economics of the use of "small" incinerators that have been installed on a "modular" basis by various towns and cities across the United States for the processing of municipally generated residential and commercial solid wastes. By definition, a "small" incinerator in this investigation is an individual furnace that burns less than 50 tons of waste during a day's operation; and "modular" infers that one or more such incinerators, each the same model and capacity, are installed in a municipal plant to achieve the desired total burning capacity.

A survey of 14 manufacturers of small incinerators disclosed that there are currently in operation 37 municipal plants that utilize the "small" incinerator, modular approach. Each plant uses, either singly or in multiples, incinerators with designed burning capacity of under 3,000 pounds per hour per machine (approximately 15 tons per ten hour day). In total 95 individual incinerators have been installed in these plants. The capacity of the machines purchased ranges from 1,000 pounds to 2,600 pounds per hour. The design capacities of the plants range from 5 tons to 105 tons per day. They have been purchased by municipalities ranging from 700 to 130,000 in population.

A basic parameter of the study was that any plant to be tested had to have been in sustained operation during the prior six months. All known manufacturers of small incinerators were invited to participate in the study. Many could not meet the criteria established for the testing program; others who had municipal incinerators installed did not choose to participate in the study.

Three towns were selected that were considered fairly representative of the small incinerator modular approach. In each case, the municipality and the equipment manufacturer agreed to participate in the testing and to permit publishing of all test results.

At each of these sites the study team conducted an investigation of the the background on the plant, the demography of the area, the local environmental problems, the economic advantages and constraints in such incinerators, and the local energy parameters. This was followed by an intensive week-long monitoring program, under normal operating conditions while burning typical municipal waste, of a test incinerator chosen at random at each plant.

At each site the design of the equipment, the buildings and the operational systems were analyzed for their affect on the efficienty of plant operations. Aspects of performance of the incinerator that were monitored included data on:waste input characterization; stack emissions; use of, as well as production of energy; detailed operating parameters; and operating costs.

The overall objective of this investigation has been to produce a report, based on the data gathered and the observations made by the study team, which will serve as a guide for municipalities considering such an approach to their solid waste management; and that can also be used for comparison purposes in future solid waste system evaluations. As this study was being concluded, additional manufacturers of modular small incinerators have evidenced interest in the growth of such solid waste processing in the municipal market.

The Monitoring Methodology

The municipal incineration plants that were investigated were located in Pahokee and Orlando, Florida,and in Siloam Springs, Arkansas. The monitoring of each plant site lasted for five consecutive days in an effort to ensure that the wastes being processed were typical of the community and that the incinerators were operating normally. The Florida plants were tested in May 1975 and the Arkansas plant in October.

For the study protocol, the methods described in the *Testing Manual For Solid Waste Incinerators* (published in 1973 by the U. S. Environmental Protection Agency) were followed.

The basic approach consists of setting aside, on the plant floor, a quantity of waste of known weight, sufficient to sustain the incinerator being monitored during each full day test period. This waste is then charged into the incinerator, using regular plant operators and equipment, as well as charging methods; noting the time each charge is put into the incinerator; and, noting the total burning time used by the plant for the entire load processed that day.

While the test incinerator is being charged, the input waste is measured, weighed, analyzed as to physical composition, and laboratory samples are extracted for detailed analysis, daily.

While the incinerator is in normal operation, stack sampling is performed to determine air emissions. The plant instruments are monitored to record temperatures, and fuel, electrical and water consumption, as well as any operational adjustments that occur.

At the completion of each day's test, the complete residue from that day is weighed and measured to determine the efficiency of reduction, and laboratory samples are collected for analysis.

If resource recovery is included in the operating parameters, such as steam production and sale from burning the waste, the efficiency of the process and its economic impact is recorded.

A daily monitoring schedule, shown in Chapter 6, was developed to perform these evaluations at each site.

All the data for the study was gathered and the performance of the tests was done by a joint team made up of personnel from: Ross Hofmann, Associates of Coral Gables, Florida, acting as overall consultants on the project; Test Services Division of Associated Service Products, Inc., Sandston, Virginia, who handled the stack testing and monitoring of the air emissions; the Office of Solid Waste Management Programs of the U. S. Environmental Protection Agency, Washington, D. C., who approved all the testing protocol, as well as contributed considerable assistance from their experience with municipal solid waste management.

At each site the plant management was able to operate the plant in its normal manner, despite the presence of a rather large team of outsiders and their necessary test equipment.

The forms that were used to collect the raw data are included in Appendix A. Within the subsequent chapters, there is a detailed account of how the individual sites were chosen and their demography; a description of their facilities, equipment and systems; an analysis of the operating procedures; the methodology of data collection; economic analyses and comparisons between the plants; and the efficiency of steam production at the Siloam Springs plant.

All of the plants studied had been in operation for a long enough time before the on-site testing to have had the opportunity to have developed some operating history. None may be termed experimental or temporary in nature, and all are representative of like plants in other communities. All have remained in normal operation and continue to incinerate waste on a daily basis since the testing period.

CHAPTER 2

THE PROCESSING OF MUNICIPAL SOLID WASTE BY INCINERATION

Many methods and systems have been designed for the processing and disposal of municipal solid wastes. They have been influenced by many factors, from environmental impact to economics. While landfilling and incineration have been the most commonly used methods, both have created certain environmental problems. Of the two methods, incineration has been the more severely criticized in recent years, due to its potential affect on air, land and water pollution, coupled with its cost implications. As a consequence, landfilling has been used in the solid waste management systems of urban areas to a far greater extent than has incineration.

From a cost viewpoint, landfilling has been cheaper than the most efficient incineration systems. However, in many urban areas acceptable landfill sites have become difficult to obtain and the expense of this method has been rising steadily, with long distance hauling from collection points and through transfer stations to a suitable site.

Solid waste management must always be viewed as a *total system*. All facets of collection, transportation, processing and disposal must be considered in any economic and environmental analysis.

Despite cost and environmental problems many municipalities have used incinerators to process their solid wastes. In the past, municipal scale incinerators have been defined[1] as those having a furnace capacity of 50 tons per day or more. In May 1972, the EPA Office of Solid Waste Management listed 193 such units in operation. This inventory was updated early in 1975 by the American Society of Mechanical Engineers (ASME), incorporating pyrolysis units and incinerators under construction[2] and gave an operating total of only 160 units. The inventory lists the known municipal incinerators by states giving the site location and describing the plant design. The majority of the plants are of large capacity. Only 41 handle less than 200 tons of waste per day; 70 handle in excess of 400 tons; the average daily capacity is 415 tons. These large municipal incinerators are concentrated in relatively few areas of the United States. New England, New York and New Jersey house over half of the total inventory for the country. The age of the units, which indicates the trend away from large-scale incineration, ranges from the early 1970's to as far back as the late 1920's -137 were built before 1965 and 67 since then - including operating and shut-down plants.

Evaluations have been published by EPA and other government agencies on the efficiency, operating costs and environmental effects of some of these municipal units. The principal study of such plants was presented to the 1970 National Incinerator Conference and covered seven municipal incinerators with analyses on the quality and quantity of solid waste they processed, the residue, the gas borne particulate emissions, the quantity of fly ash, and the economics involved in the purchase and use of these large machines.[3]

A major need uncovered from these evaluations was the requirement for more stringent air pollution control codes. The seven municipal incinerators reported to the Incinerator Conference showed analyses of 4 to 17 times the emission rate the EPA thought desirable, and ranged from a low of 0.30 to a high of 1.35 grains. Most older incinerators are in this range, because of a virtual absence of air pollution control equipment. EPA has established particulate emissions of 0.08 grains per standard cubic foot of dry flue gas corrected to 12% CO_2, as a standard to be met by "large" incinerators.

The potential for pollution has also existed for the land and the water from large scale residue generation and large volume generation of scrubbing and quenching water.

Another constraint to the construction of large scale incineration is in the cost factors. Large incinerators, operating 24 hours per day, infer large quantities of waste. This, in turn, means long hauls and increasingly expensive transportation costs as part of the total picture required to generate such quantities. Engineering and construction costs of the large plants, like all major construction projects, have escalated trememdously in the past 20 years. Mechanization and automation have sophisticated plant design and further increased costs of design and construction.

The combustion designs of these large units almost universally incorporate an excess air principle in the primary chamber to control the heat in the emitted gas stream. This increased volume of air aggravates the problem of air pollution control. Expensive and rather complicated pollution control devices must be installed to control the emissions - either mechanical in nature; or utilizing water washers or scrubbers. Due to the high expense, most large scale plants have not yet installed such air pollution control equipment, and are being criticized accordingly for their emission rates.

The combined effect of these capital cost elements has been that the ownership and financing costs for the large plants range from 23 to 54 percent[4] of the total operating cost structure.

Despite these environmental and cost problems that have faced municipal incineration, many communities have felt that if different design approaches were taken, incineration could be both environmentally and economically feasible as a means of processing urban wastes. This has been based on studies of the "small" incinerators that have been developed in recent years. Most of these units are constructed in a factory, on a packaged basis. They have burning capacities of from 500 to 3,000 pounds per hour. By utilizing controlled air designs, and by using auxiliary fuel to burn off particulate emissions, they are able to meet EPA's air pollution control recommendations.

While the majority of the small incinerators have been purchased by industry and by institutions, for on-site destruction of wastes, during the past five years an increasing number of municipalities have been investigating their use. The sizes being considered have had charging rates of from 1,500 to 3,000 pounds per hour (processing rates of from 9 to 15 tons per day).

To provide the total burning capacity required by a municipality, the system was developed of installing such units in modules of two to eight within a single plant. Such a modular approach has provided greater site flexibility for small and medium sized cities than exists with the large volume plants. More importantly, it has provided flexibility for expansion as the city expands its waste generation. Expanding communities can be put on a "pay-as-you-go" basis, with lower capital investment than found in large incinerator plants, and a consequent easing of tax burdens for capital repayment.

For certain larger communities, spread out over a large land area, the modular plant approach has permitted the erection of relatively inexpensive satellite plants. These have resulted in reduced hauling costs to the incinerator from pick-up points or transfer stations.

The design standards of the small modular incinerators have proven that they efficiently process residential and commercial waste. The volume and weight reduction ratios are comparable to the large scale machines. With few moving parts, maintenance problems, and hence costs, have been minimized. As they do not employ water washers or scrubbers to achieve their low air emission rates, or water quenching systems to cool the ash residues, the cost and environmental aspects from the use of water with large incinerators have been eliminated.

Compared to large scale incinerators, the use of auxiliary fuel in the smaller machines can create a cost problem. If the combustion engineering has not been done efficiently, large quantities of such fuel could be burned in order to achieve the desired air emission rates.

The use of automation has been kept to a minimum in the small incinerator designs to keep down construction costs. Very few units have automatic ash removal. Without this feature they must operate on a 24 hour cycle; the ash residue must be removed by an operator after building up inside the chamber for a given number of hours. The incinerator is normally cooled down to permit this. This has a direct effect on the operation. It means additional use of fuel to warm up the incinerator so it can be used once more. This, in turn, results in thermal shock and some deterioration of the refractory, when it is cooled and heated on a daily basis. As clean out of the ash is done by hand, there is always the danger of damaging the refractory lining in the process. As the ash is dry during clean out, it could be hot and potentially dangerous for the operator. If done carelessly in a windy area, it could create a dust cloud.

None of these design aspects are serious. Most have been solved in the institutional and industrial fields, where the buyers have been agreeable to spending additional sums to automate the equipment.

Many researchers have questioned the logic of destroying resources and not obtaining every possible residual value from them. They have investigated various possibilities of extracting such values from waste, at the source, at some form of transfer station, or at an incinerator plant by burning the waste as a fuel to create energy for the production of steam or electrical power.

Concurrent with the introduction of modular plants for municipal incineration has been the introduction of waste heat recovery systems. These systems directly produce steam in special boilers. The process as currently marketed has proven to be efficient and economical, requiring only relatively small amounts of auxiliary fuel (gas or oil) to start and maintain the process. The net result has been to recapture the major costs of operating the incinerator, through the sale of the steam produced.

During the present study, our surveys showed that many municipalities are investigating the practicality of installing modular small incinerator plants to process their residential, commercial and some of the industrial wastes. Originally, investigations by most communities concentrated on the advantages of incinerators for volume reduction. During the past year, the emphasis has switched to examining the potential advantages of the plant as a steam producer for local industry or municipal use. Both approaches have been covered in the report that follows.

CHAPTER 3

REFUSE GENERATION

General

The incinerator units tested were specifically designed to burn municipal waste. The designers and municipal sanitation officials have normally made pre-installation estimates of the types and quantities of waste they will be receiving from their residents in the foreseeable future; ranging from residential refuse with an approximate heating value of 5,000 Btu per pound as fired, to commercial refuse as low as 4,000 Btu, to industrial refuse that may run well over 9,000 Btu per pound. Due to increasing amounts of paper and plastic in the waste stream, the heating value of municipal waste has been mounting steadily during the past ten years. The designers of the modular municipal units have planned their systems so that they will handle waste ranging from below 4,000 Btu per pound, to that rising over 9,000 Btu per pound, in the mix that is charged each day, including moisture.

Cursory study of municipalities, combined with the detailed findings from the present survey, reveals that it is difficult and often misleading to generalize on both the quantities and characteristics of waste being generated from one community to another.

The present study indicates that there are important differences between communities. The total waste quantity generated per unit of population, residency, or employment varies between communities in relation to their size, social and economic make-up of the residents and workers as well as transients, and the extent and type of commercial and industrial activity. Climate, living styles, and seasonal variations also affect the quantities generated. Make-up of the waste not only varies between communities but varies at different days of the week and seasons of the year, within the same community.

Such variations in waste stream make-up have a definite affect on planning for resource recovery, such as metal, glass and paper recovery, or the production of steam from burning the waste.

The municipalities selected for detailed analysis in the present study differ somewhat in their solid waste management, collection and reduction methods. From a systems aspect, the engineering of the municipal plants, their specific operational methods, and the design of the various components also vary from plant to plant to a degree.

While by no means representing a statistical sampling of such plants in the U. S., the three communities selected for the present study do reveal the solid waste problems found in many of the smaller and medium sized communities. The survey methods and the results can be applied as a guide for evaluating the use of "small" incinerator modular plants in hundreds of other municipalities: from such aspects as waste generation quantities and types, plant and equipment design and operation, environmental effect, and the economics of capital purchase and operational costs, including resource recovery.

Pahokee, Florida

Demography

The Town of Pahokee, Florida is a rural marketing center, incorporated in 1922, and now covers an area of five square miles. The population early in 1974 was 5,994 and is projected by the Palm Beach County Area Planning Board at 6,400 by May 1975.

As of April 1974, dwelling units were projected at 1,864. Contributing further to residential waste is one motel, one inn and five year-round multi-dwelling units, with approximately 10 apartments each.

The waste from one 60 bed hospital is handled by the municipal facilities. Educational facilities include one elementary school; one middle school; one junion-senior high school; and one private elementary school. There are eleven churches and 20 clubs and organizations which include Lions, Rotary, Boy Scouts, all of which send waste to the municipal facilities.

Generating commercial waste are seven sit-down restaurants; two fast service establishments; one hardware store; five general merchandise stores; nine food stores; two automobile dealerships; three used car lots; five gas stations; five apparel stores; two furniture stores; two drug stores; and one bank.

The leading industry is sugar production with revenues that top $200 million per year. Food processing also encompasses potatoes, greens, and other vegetables. Virtually all food production waste is processed within each plant. Other industries include ice plants, chemical and fertilizer plants and welding and machine shops.

Geographic Conditions

Pahokee is located on the southeastern shore of Lake Okeechobee. The town is 45 miles west of West Palm Beach and 90 miles northwest of Miami. The average mean winter temperature is 71 degrees F and the average summer temperature is 81 degrees F. Pahokee's wet season begins in late May and ends in late September. The average annual rainfall is 56 inches.

Operation of the Municipal Sanitation Department

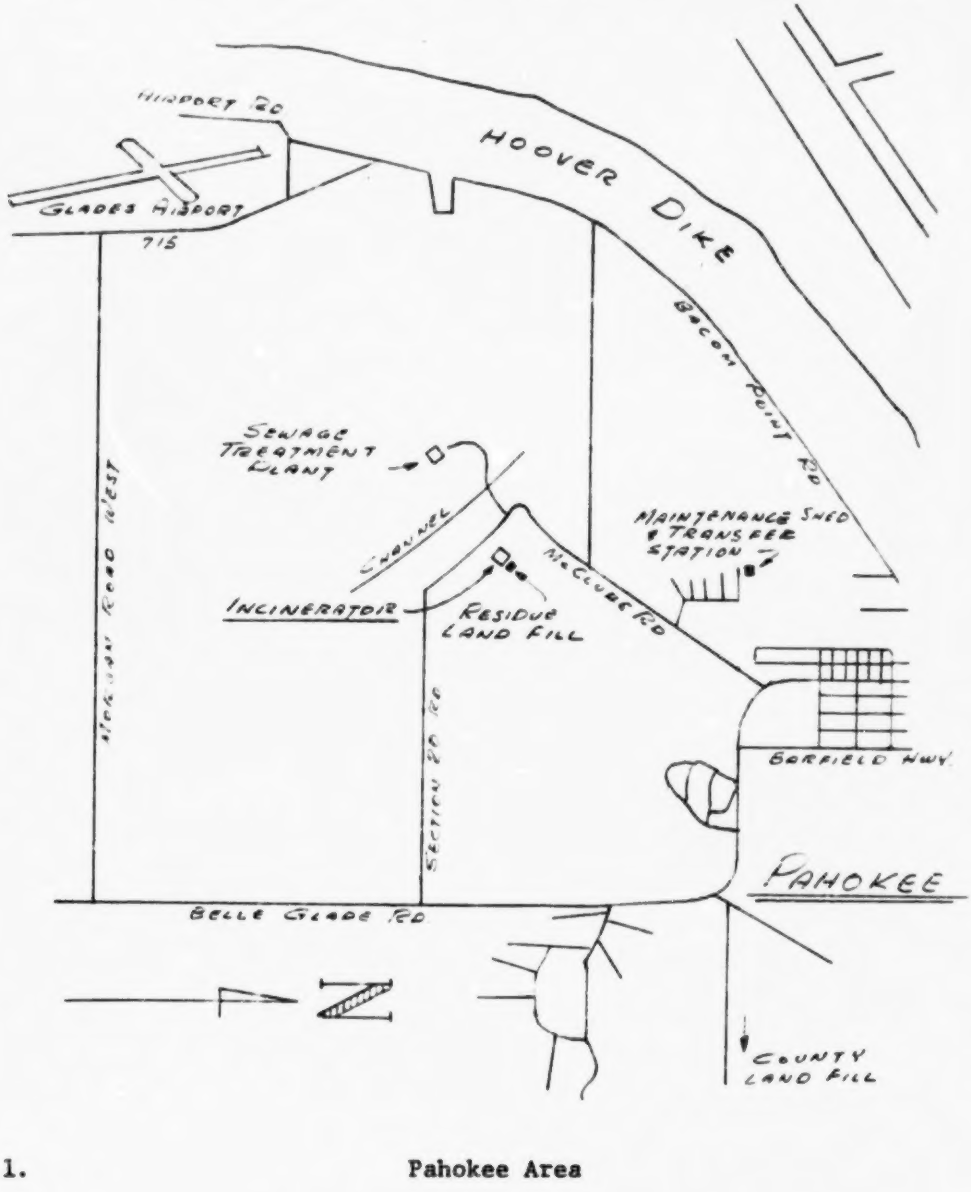
Pahokee has a Sanitation Department operated under a Director of Public Works and provides commercial and residential solid waste collection as well as a municipally-owned transfer station and an incinerator plant. There is a financial agreement with West Palm Beach County for use of the county landfill located three miles from downtown Pahokee, or 1/2 mile from the town limits. The county charges 30 cents per cubic yard for all hard fill and solid waste non-combustibles (such as metals and glass) delivered to the landfill.

All combustibles are delivered to the incinerator plant, which was installed and operational by May 1974. It was designed and manufactured by Consumat Systems and contains two 8.5 ton per day Model C-550M incinerator modules with automatic loaders, giving a total plant capacity of 17 tons per 10 hour day.

Residential collection is by a container-train which operates every other day. Two sanitation men pick up from each residence by means of several dumpster carts pulled together behind a pickup. When full, the carts are left at the transfer station. The waste appearing combustible is transferred to a front loading compactor which, in turn, delivers full loads to the incinerator, two to three times a day. Commercial collection occurs on the alternate days.

Combustibles, as well as small non-combustibles, are incinerated. Garden waste over four feet in length, and large non-combustibles are hauled to the county landfill from the transfer station. The hospital delivers its contaminated and pathological waste to the incinerator. Other wastes from the hospital are picked up by the town on a commercial account. Four out of six parks, within the town limits of Pahokee, have accounts with the town for pickup of solid waste, excluding garden and non-combustible wastes which are delivered to the county landfill.

Map 1 shows the relationsips of the solid waste management facilities.


AIRPORT RD
GLADES AIRPORT
715
HOOVER DIKE
BACOM POINT RD
SEWAGE TREATMENT PLANT
CHANNEL
INCINERATOR
RESIDUE LAND FILL
McCLURE RD
MAINTENANCE SHED & TRANSFER STATION
[illegible] ROAD WEST
SECTION 20 RD
BARFIELD HWY.
PAHOKEE
BELLE GLADE RD
N
COUNTY LAND FILL

Map 1. Pahokee Area

Orlando, Florida

Demography

The City of Orlando was incorporated in 1875. Situated in Orange County, Florida, it has a 1975 population of 120,000. The total area is 42 square miles. Orlando has a diversified economy consisting of commercial establishments, industries, manufacturing plants, motels, hotels, hospitals, schools, and single/multiple occupancy residential areas. Construction of motels and residences has been extremely heavy over the past five years. There are 110 motels and hotels and 41,774 single and multiple households as of May, 1975. Generating additional wastes are seven hospitals totalling 3,000 beds, 37 primary/secondary educational institutions, and one junior college.

Commercial wastes are generated by 70 hardware stores; 41 general merchandise stores; 164 food stores; 50 automobile agencies; 215 gas stations, 101 apparel stores; 105 furniture stores; 231 eat and drink restaurants; and 35 drug stores. Estimates for 1975 indicate total retail sales at $1,025,068,000.

Orlando and vicinity has industries with a total of 155,300 wage earners that produce waste for the Sanitation Department, including electronics, aerospace, and food processing plants. The latter use large quantities of potatoes and corn, but have in-house disposal-clarifying systems.

In five years, total daily solid waste generation per resident is estimated to have risen from 4.5 pounds to 7 pounds, according to the Superintendent of Refuse Collection. It is also estimated that motels and hotels are now accumulating on "full" occupancy days as much as 5.5 pounds of waste per day per room, but have large seasonal variations running from 100% to 40% occupancy. At present, due to a combination of climate (the wet and dry seasons), plus the number of transients in the motels and hotels, there occurs a total waste load variance as much as 100%: from 300 to 600 tons daily.

Geographic Conditions

Orlando is situated in a flat, sub-tropic area surrounded by 2,000 lakes. Located 245 miles from Miami, 85 miles from Tampa/St.Petersburg, and 140 miles from Jacksonville, in the center of Florida, the mean average temperature is 68 degrees F in the winter and 80 degrees F in the summer. The wet season begins late May and ends late September. The average annual rainfall is 54 inches. Conditions permit garden waste to be generated every month of the year.

Operation of the Municipal Sanitation Department

The Department of Sanitation handles the disposal of a daily average of 425 tons of solid waste. The Superintendent of Refuse Collection divides the city into four collection districts--southeast, southwest, northwest, northeast- for control of this operation.

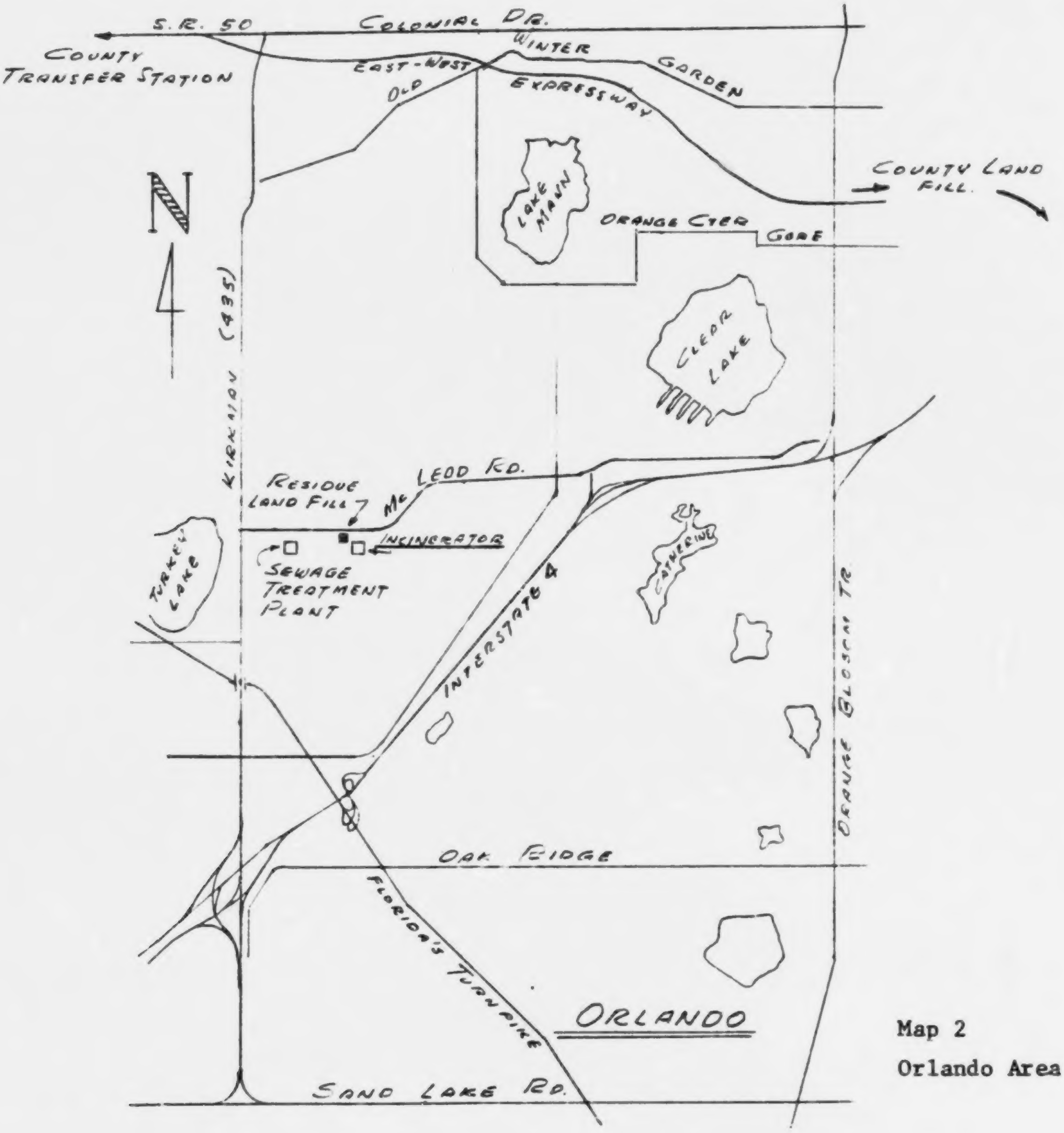
Currently a transfer station is operated by Orange County nine miles due west of downtown Orlando and used by the city for part of its waste load. Long-range planning by the county and the city calls for five such transfer stations to be established in the various quadrants of the city and county, in order to reduce hauling costs. To date, only the western unit is in operation.

The city transports its solid waste from the northwest quadrant to the existing transfer station and is charged at a rate of $2.60 per ton by the county. The transfer station has a maximum capacity for waste reception of 1,200 tons per day. After transfer to large county tractor-trailers, the waste is then hauled to a County landfill area located 18 miles southeast across town. Waste from the eastern half of the city is normally transported directly to this same County landfill.

The southwest quadrant of Orlando is estimated to have a population of approximately 30,000 and to contribute about one-quarter of the total community waste load. Due to the proximity of Disney World southwest of this quadrant, this area has been expanding very rapidly with motels, hotels, light commercial establishments and residences. Four years ago it was decided to install and operate a municipal incinerator in the center of this quadrant to handle the expanded waste generation.

The plant, completed in May 1974, contains eight identical Consumat Model C-760M incinerators with L-518 automatic loaders. Each incinerator is rated at 12.5 tons per 10 hour day, giving a combined total capacity of 100 tons per day. The plant was designed to accept commercial, residential and some industrial wastes. In addition, non-pathological waste is accepted from up to three hospitals on the fringe of this sector.

The collections are picked up from the generating sources in 20 yd.^{3} compaction trucks and hauled directly to the incinerator. In practice, the Sanitation Department controls the amount delivered to the incinerator plant and "juggles" the truck routing. The maximum acceptable solid waste at the incinerator is 105 tons daily. Any excess is sent to the transfer station. If the day appears light in waste collected from the southwest area, waste is brought from other quadrants or from fringe areas to level the load up to the optimal 100 tons. Map 2 shows the solid waste management facilities.


S.R. 50
Colonial Dr.
County Transfer Station
Winter Garden
East-West
Old
Expressway
County Land Fill
N
Lake Mann
Orange Cter Gore
Clear Lake
Kirkman (435)
Residue Land Fill
McLeod Rd.
Incinerator
Sewage Treatment Plant
Turkey Lake
Catherine
Interstate 4
Orange Blossom Tr.
Oak Ridge
Florida's Turnpike
Orlando
Sand Lake Rd.

Map 2
Orlando Area

Siloam Springs, Arkansas

Demography

Siloam Springs was incorporated in 1880. Located in Benton County, Arkansas, it has a population of 6,500, and covers an area of twenty square miles. Its waste system is combined with the nearby town of Gentry to give a total population served of 8,000. The combined area has a diversified economy. Residential waste is generated by 2,376 homes in Siloam Springs and an additional 500 homes in Gentry. There are no high rise condominiums or multiple occupancy residential areas. Siloam Springs has six primary educational institutions with 1,912 students, one university with 590 students, one 80 bed hospital and six motels with 161 rooms generating wastes. Other wastes are generated by 21 churches, several clubs and organizations which include Lions, Rotary and Kiwanis, one medical clinic, five physicians, four dentists and 105-bed nursing home. Gentry has a primary school and one 15 room motel.

Contributing to industrial waste in Siloam Springs are eleven industries employing 1,628 people. These include a food canning plant, a process plant for poultry, a chicken hatchery, and seven manufacturers that produce automobile tires, telephone and communication cables, plastic pipe, steam cleaners, cutting tools, wheel and brake drums, upholstered chairs, and submersible motors. Gentry has a kitchen cabinet plant employing 86 people.

Commercial waste in Siloam Springs is generated by eight fast-food service restaurants, six sit-down restaurants, two hardware stores, eight general merchandise stores, ten food stores, five automobile dealers, five used car lots, 25 gas stations, seven apparel stores, three furniture stores, five drug stores and two banks. Gentry adds an additional 70 commercial accounts.

Geographic Conditions

Siloam Springs is located in northwestern Arkansas, one mile from the Oklahoma state line and 28 miles northwest of Fayetteville. The average mean temperature in winter is 40 degrees F and in summer 84 degrees F. The area is 1,183 feet above sea level with an average annual rainfall of 58.4 inches.

Operation of the Municipal Sanitation Department

The arrangement for operation of the plant and the municipal collection of the solid waste is quite different in Siloam Springs from the other municipalities examined. It represents a partnership between the municipality and a local industry, an incinerator plant designer and manufacturer, and a distributor of the equipment and systems. This came about as a result of the current energy shortage in the U. S., and pressures to locate alternate sources for energy, combined with the community's desire to improve its solid waste management.

A major manufacturer and Siloam Springs employer, the Allen Canning Company, requires substantial quantities of steam for its food processing operations. Its direct-fired boilers use natural gas, which has almost tripled in price during the past two years; there is also the possibility of gas rationing. The company was agreeable to placing a long-term contract for the purchase of steam from the municipality, at rates tied to the going price of such energy, providing a satisfactory supply could be developed. The municipality, anxious to maintain full employment in the community, completely agreed with the concept.

The town, like many others, had been faced with solid waste management and disposal problems. The soil in many parts of Arkansas is rocky and presents difficulties for operating sanitary landfills. Waste loads have been increasing with population and commercial growth, as have the disposal costs per ton. Further, many members of the Town Council felt that the wastes being generated represented too valuable a resource to be simply destroyed by incineration or buried in a landfill. If incineration with waste heat energy recovery could be efficiently combined, it would appear that both industry and the town would benefit.

Allen Canning Company agreed to lease a plot of land, adjacent to its plant, to the city for $1.00 a year, on a twenty year lease with renewals, for construction of an incinerator plant with a steam recovery system.

The town agreed to provide funds to purchase the necessary equipment and systems, including the plant structure and site improvements.

When the entire technical, operational and financial package was put together, it was projected that the income from the sale of steam, coupled with that from waste collection fees, was sufficient to cover all operating costs and liquidate the capital investment over a sixteen year period. The city was able to sell bonds at a relatively low interest rate, to finance the complete investment. Appendix E contains the complete Agreement between the town and the canning company.

The first phase of plant construction consists of a 21 ton per 10 hour day plant with two 10.5 ton per day Model C-550MS Consumat incinerators with automatic loaders. The incinerators are connected to waste heat recovery boilers. Initial steam production per unit is guaranteed to be at least 50,000 pounds per day at 125 psig. (total 100,000 lbs.). The boiler steam output is piped through an insulated line approximately 450 feet, across a street and into the steam supply system of the Allen plant. Operation of the system commenced in June, 1975.

All commercial and residential waste generated by Siloam Springs and neighboring Gentry is collected under a contract management system and trucked to the incinerator plant. The city collects the waste fees for the service from the residents and commercial establishments. The arrangement is now being broadened to include wastes from certain industrial plants.

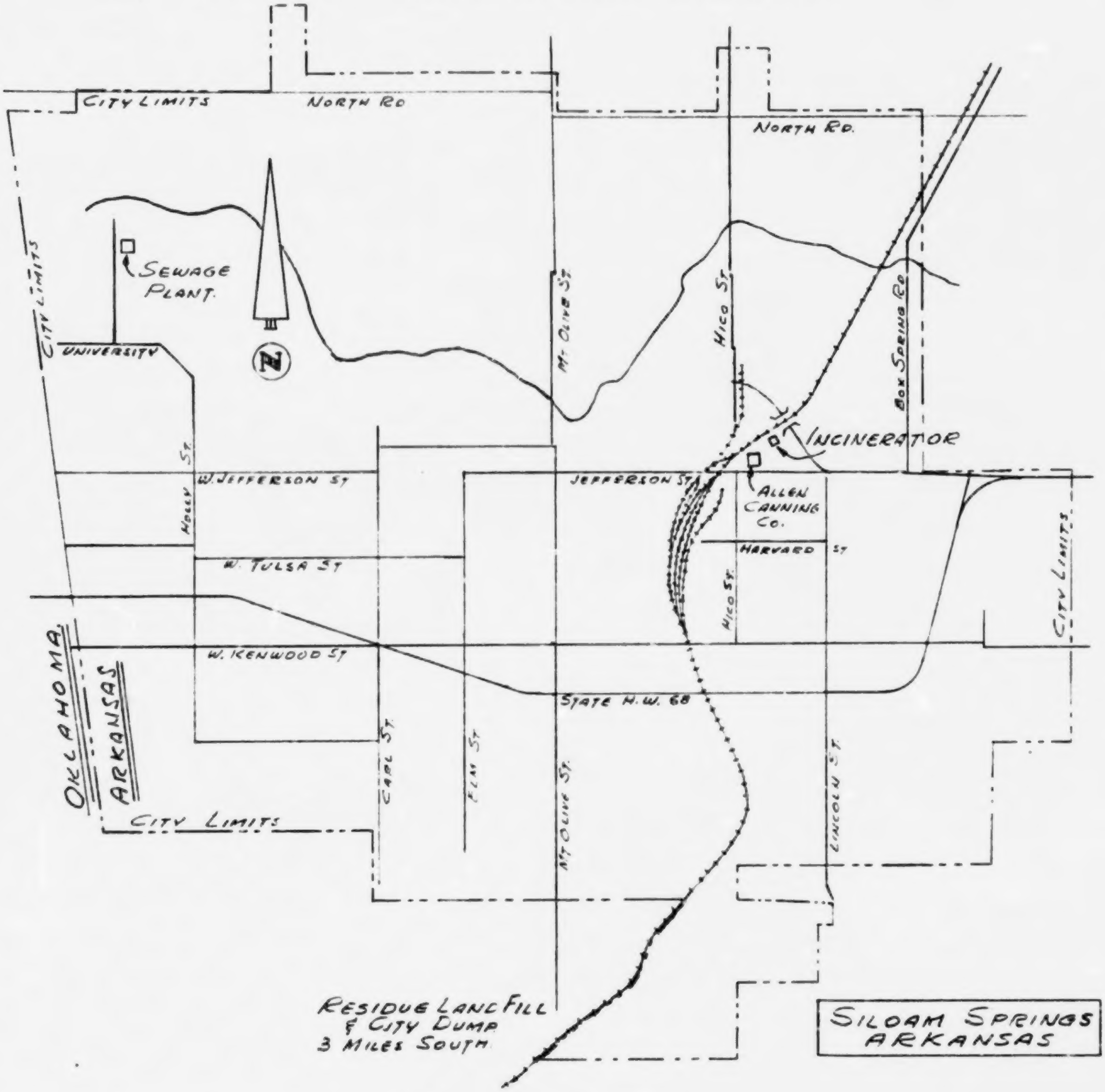
The incinerator distributor was given a management contract for at least the first two years of operation of the incinerator-steam plant, to ensure technical efficiency in its initial operation. The city also established, by ordinance, a Sanitation Facilities Commission to act as liaison between the City Council and the management of the waste disposal and energy production system.

The city has a landfill and has retained it for the disposal of large items that are non-combustible, or that might cause problems in the incinerator operation, either due to their size or chemical nature (such as cans of lacquer thinner). At present, the landfill is also used for disposal of the incinerator ash residues. In the future, these residues may be stockpiled and used for road repairs.

Under the present contractual arrangement, waste collection is managed by the incinerator plant supervisor utilizing a driver foreman and six laborers. Collection of solid wastes is bi-weekly utilizing three compactor trucks with the town divided into two collection districts. Combustible waste is delivered directly to the incinerator from the pickup points. Bulk items and non-combustibles go directly to the landfill.

Gentry and Siloam Springs have ordinances that require curbside pick-up. Kitchen waste, leaves, grass, small yard trimmings, shrub and tree trimmings less than 2 inches thick, waste paper, cans and glass must all be placed in plastic bags or tied in bundles no larger than 4 foot square and weighing no more more than 50 pounds. Large tree trimmings over 2 inches thick, large non-combustibles (such as metal parts and appliances) are collected on special request by the town and taken to the landfill.

Map 3 shows the solid waste facilities of Siloam Springs.


CITY LIMITS
NORTH RD
NORTH RD.
SEWAGE PLANT.
UNIVERSITY
CITY LIMITS
MT OLIVE ST.
HICO ST.
BOX SPRING RD
INCINERATOR
HOLLY ST.
W. JEFFERSON ST
JEFFERSON ST.
ALLEN CANNING CO.
HARVARD ST
W. TULSA ST
HICO ST.
CITY LIMITS
W. KENWOOD ST
STATE H.W. 68
OKLAHOMA
ARKANSAS
CARL ST.
ELM ST.
MT OLIVE ST.
LINCOLN ST.
CITY LIMITS
RESIDUE LAND FILL & CITY DUMP 3 MILES SOUTH
SILOAM SPRINGS ARKANSAS

Map 3 Siloam Springs Area

CHAPTER 4

TECHNICAL DESCRIPTION OF EQUIPMENT AND PLANTS

In each of three plants tested, the incinerators were factory engineered and constructed, and shipped to the sites as pre-packaged systems. All three plants were modular in design, housing from two to eight units to achieve the desired plant size and total processing capacity. The major differences between the plants consisted of building design and plant equipment (such as scale house), size of plant floor and building, charging mechanisms and controls, and energy recovery systems. Minor differences were in the auxiliary fuels (natural gas, propane gas, or oil) used. At each plant, the incinerators operated on basically the same controlled air principles as discussed below.

Theoretical Considerations

The design of each of the tested incinerators is based on the controlled air principle. Two refractory lined and insulated chambers, designated primary and secondary, are used for the combustion process, and a refractory lined stack is used to duct the exhaust gases to the atmosphere. The waste is charged into the primary chamber where ignition takes place. Once preset conditions of temperature and time have been achieved, the primary chamber auxiliary fuel burners are turned off automatically.

A reducing atmosphere (insufficient oxygen for complete combustion) is maintained in the primary chamber and the gas velocity is kept very low to minimize the entrainment of particulates in the effluent gas stream. This gas is introduced into the secondary chamber through a zone of turbulent airflow where the combustion process is completed. An oxidizing atmosphere (excess air) is maintained in the secondary chamber to insure complete oxidation of the combustible material in the gas. The effluent from the secondary chamber flows into the stack through an air induction section. The inducer serves to cool the hot gas stream prior to its exit from the system. The unit operates at a slightly negative pressure which insures that any infiltration is directed into the system.

The operating regime of both the primary and secondary chamber is shown schematically in Figure 1. The curve shows a characteristic combustion gas temperature variation as a function of air-fuel (waste) ratio. Starting in the reducing region (insufficient oxygen), the temperature will increase as the air-fuel ratio is adjusted toward the chemically correct mixture (stoichiometric).

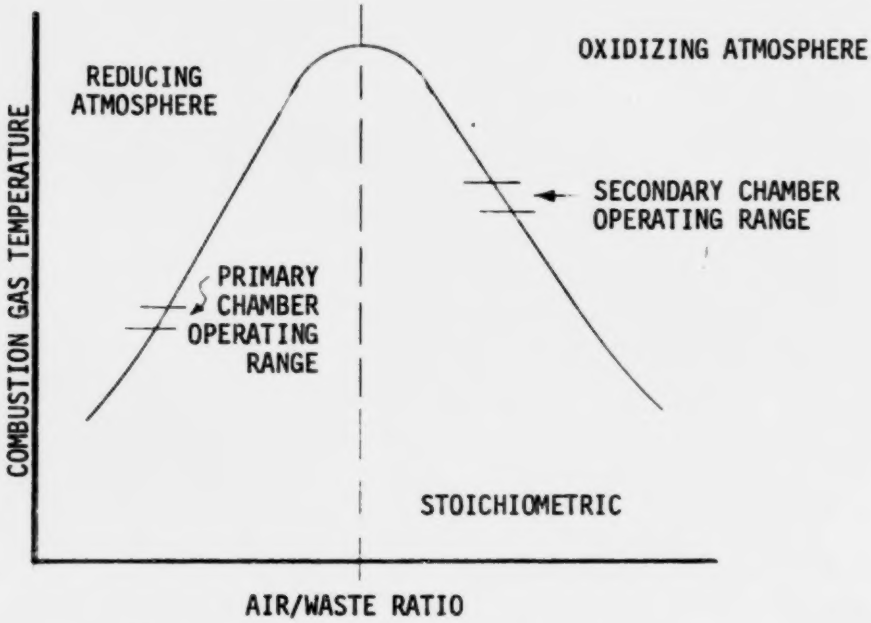
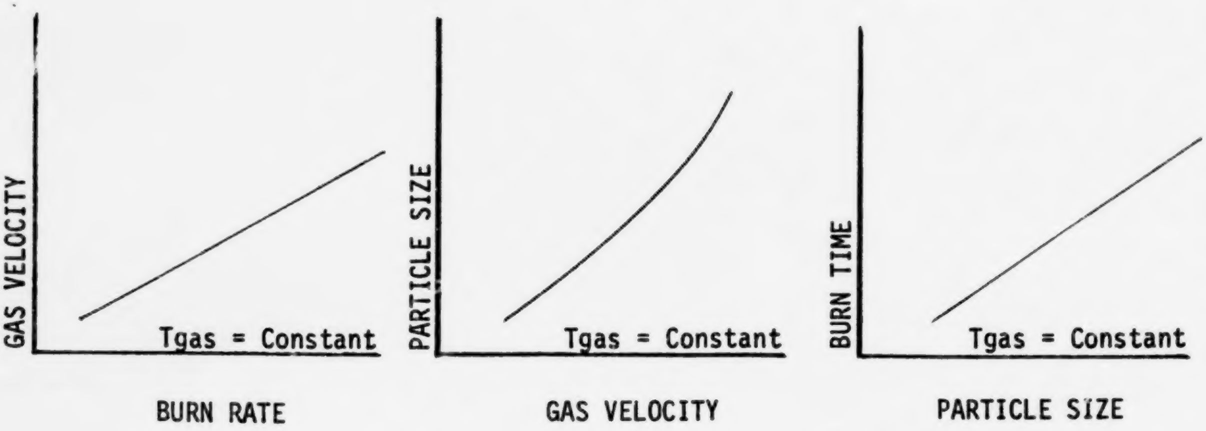


Figure 1. SCHEMATIC OF DESIGN TEMPERATURE OPERATING RANGE

The maximum temperature is attained at a ratio near the stoichiometric value. The operating range of the primary chamber is superimposed on the curve in the reducing region. As the air-fuel ratio moves into the oxidizing region (excess air), additional air serves only as a dilutent and the gas temperature is reduced. The operating range of the secondary chamber is superimposed on the curve in the oxidizing region for illustration purposes.

The relationship between the physical parameters of the system (the volumes and areas involved, and operating parameters; the operating temperatures, burn rate and gas flow rates) are important in designing for high performance in terms of maximum destruction rates, minimum emission rates, and equipment reliability. The general simplified relationships are shown schematically in Figure 2.



A. PRIMARY CHAMBER GAS VELOCITY   B. ENTRAINMENT VELOCITY   C. RETENTION TIME REQUIREMENT

Figure 2 SCHEMATIC OF DESIGN PARAMETER RELATIONSHIPS

Figure 2. Curve "A" shows the variation of gas velocity with burn rate for a constant gas temperature and fixed equipment sizing. The effect of gas velocity on emissions is illustrated in Curve "B". This curve shows that the higher the gas velocity, the larger the particles which can be entrained in the gas stream. The effect of particle size on design is shown in Curve "C". This shows that the larger the particle size, the greater the retention time required for complete combustion. Taken together, the curves indicate the need to balance the design burn rate (gas velocity) with the secondary chamber volume to insure that sufficient retention time is available to completely burn the particles which can be entrained in the effluent gas stream.

Design Considerations For The Incinerators

The theory just described is translated into practice only through properly designed equipment and integrated systems and controls. The nature of municipal incineration dictates the necessity for rugged construction and simplicity of operation. The environmental standards that must be met under current EPA recommendations, as well as state and local codes, dictate the necessity for proper loading and properly controlled temperatures to ensure minimal particulate emissions.

The general designs of the incinerators that were tested are shown in Figure 3 for Pahokee, Florida; Figure 4 for Orlando, Florida; and, Figure 5 for Siloam Springs, Arkansas.

In each case, it will be noted, the incinerators had many points in common for the primary and secondary chambers and stack sections. All the incinerators employed automatic loaders, hydraulically operated with a ram feeder, and remotely controlled by the operators of the loading vehicles that moved the waste from the plant floor to the loader. Figure 6 illustrates the automatic loader sequence at Pahokee, and Siloam Springs, while Figure 7 shows the sequence used at Orlando.

Batch-fed municipal units of this type have five basic modes of operation: warm-up, charging, burn-down, cooling and clean-out. All such units can be charged at a greater rate than the waste can be burned. The waste in the unit at the end of the charging day is consumed during the burn-down period. (This type of operation is not to be confused with continuous charging, 24 hours/day, where the charge rate and burn rate are equal and the ash is removed continuously).

Because incinerators of this design operate with auxiliary fuel, they have automatic controls to regulate the amount of fuel used. These involve strategically placed thermocouples to record temperature fluctuations within the two chambers; valves to control the flow of auxiliary fuels and dampers to control air (oxygen) inlet. They also utilize a sequence timer to automatically shut off the burners within a set time duration (usually three hours) after the last charge: - the timer is set by each closing of the loader fire door, continually resetting until loading ceases.

The primary chamber blower continues to operate after the burners shut off, unless the power is turned off. This is done to assure complete burn-down and to help cool the primary chamber before clean-out the following morning.

Obviously, for good waste reduction and environmental effect, temperatures, pressures, and air control are critical. Ideally, to minimize fuel consumption, operating temperatures should be arrived at rapidly. By a combination of auxiliary fuel injection and air control, during warm-up the temperature in the primary chamber rises to approximately 1400°F and in the secondary to approximately 1800°F. The controls maintain the proper mixes of air and auxiliary fuel, combined with the heat output of the burning waste, to retain these temperatures during the charging and burn-down periods.

The primary chambers of the tested units were equipped with water spray systems to control temperatures. The spray nozzles are protected from the usual operating temperatures by a constant drip of water through the system. The sprays are automatically actuated when temperatures in the lower chamber exceed preset conditions.

The materials of construction for such pre-packaged units have to lend themselves to the economic advantages of manufacturing in a factory, yet must be able to take the abuse as well as heavy duty use that is experienced in municipal operations. The outer shell and end domes in the test units were fabricated from 1/4 in. steel plate. All weight loads were carried through bulkheads formed from heavy structural steel channel and T-beams. The primary and secondary chambers and the stack sections were fully lined with castable, high temperature refractory, as was the full-swing end dome, and this was, in turn, backed up by mineral block insulation to minimize heat loss. Because clean-out was performed in the test units by long rakes mounted on tractors, the refractory in the primary chamber suffers considerable abuse. The lower section of this chamber was, in each case, lined with firebrick to reduce the erosion from clean-up.

The control panels and contactor boxes were mounted remotely from the incinerator, within the plant building adjacent to each loading platform. Pendant boxes were also located at the door to the loading platforms so that the operators can activate the automatic chargers without leaving their vehicles.

Burner safety controls, for each unit, appeared well designed, and the gas-fired models met code requirements.

The designs have been simplified to the point where maintenance requirements are quite minimal; such as lubricating latches and hinges on the doors; checking the blower intakes for foreign matter; visually checking for gas or fuel leaks, cleaning the air ports and air plenum holes, and cleaning the spark ignitors and flame sensors monthly. The hydraulic loaders require normal visual checking daily and weekly for lubrication and hydraulic fluid levels. If waste heat boilers are included then the boiler tubes should be visually checked at least weekly.

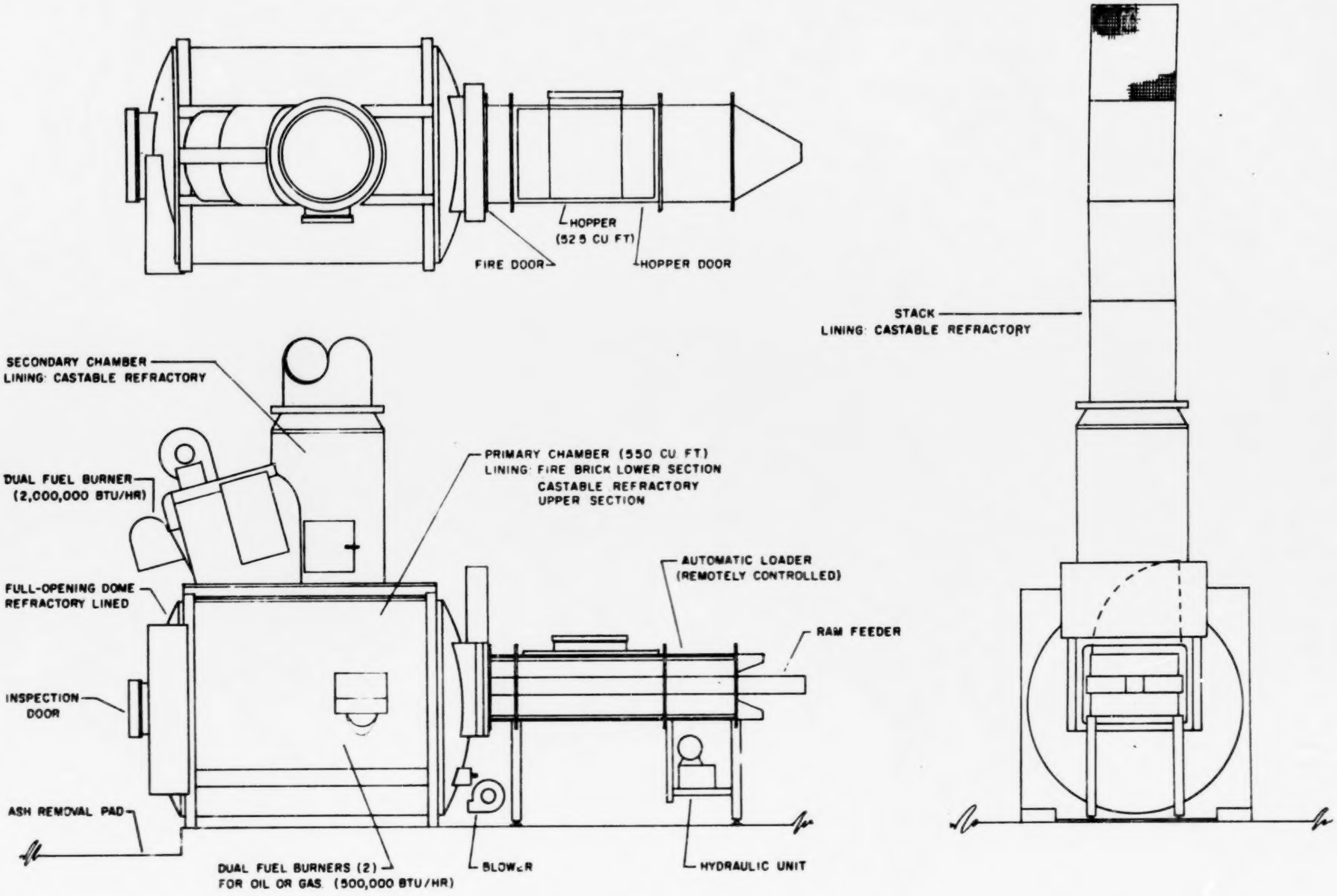

HOPPER
(52.5 CU FT)
FIRE DOOR
HOPPER DOOR
STACK
LINING: CASTABLE REFRACTORY
SECONDARY CHAMBER
LINING: CASTABLE REFRACTORY
DUAL FUEL BURNER
(2,000,000 BTU/HR)
PRIMARY CHAMBER (550 CU FT)
LINING: FIRE BRICK LOWER SECTION
CASTABLE REFRACTORY
UPPER SECTION
FULL-OPENING DOME
REFRACTORY LINED
AUTOMATIC LOADER
(REMOTELY CONTROLLED)
RAM FEEDER
INSPECTION
DOOR
ASH REMOVAL PAD
DUAL FUEL BURNERS (2)
FOR OIL OR GAS (500,000 BTU/HR)
BLOWER
HYDRAULIC UNIT

Figure 3. MUNICIPAL INCINERATOR MODULE

PAHOKEE, FLORIDA

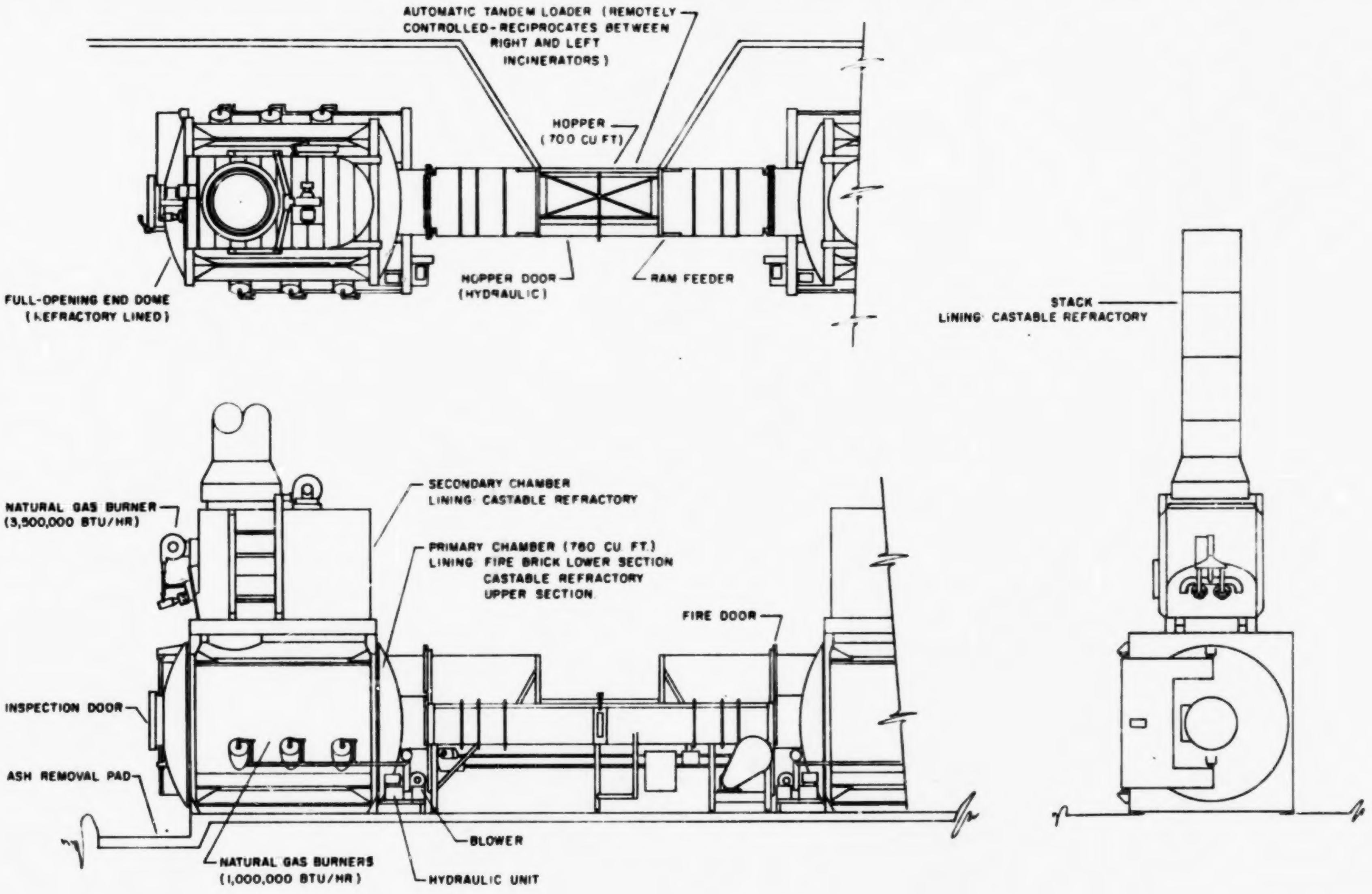
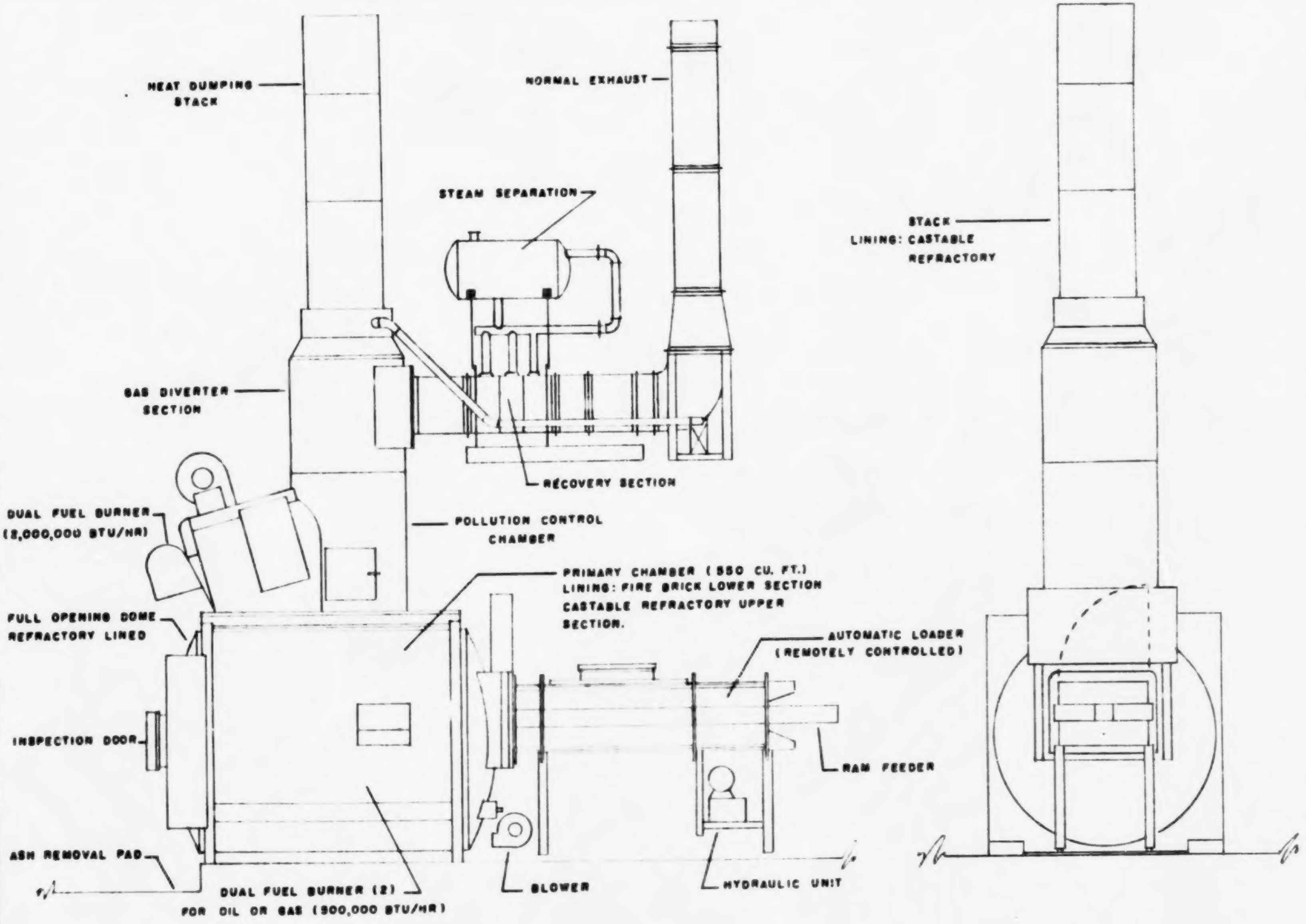

AUTOMATIC TANDEM LOADER (REMOTELY CONTROLLED-RECIPROCATES BETWEEN RIGHT AND LEFT INCINERATORS)
HOPPER (700 CU FT)
HOPPER DOOR (HYDRAULIC)
RAM FEEDER
FULL-OPENING END DOME (REFRACTORY LINED)
STACK LINING: CASTABLE REFRACTORY
NATURAL GAS BURNER (3,500,000 BTU/HR)
SECONDARY CHAMBER LINING: CASTABLE REFRACTORY
PRIMARY CHAMBER (760 CU. FT.) LINING: FIRE BRICK LOWER SECTION CASTABLE REFRACTORY UPPER SECTION
FIRE DOOR
INSPECTION DOOR
ASH REMOVAL PAD
BLOWER
NATURAL GAS BURNERS (1,000,000 BTU/HR)
HYDRAULIC UNIT

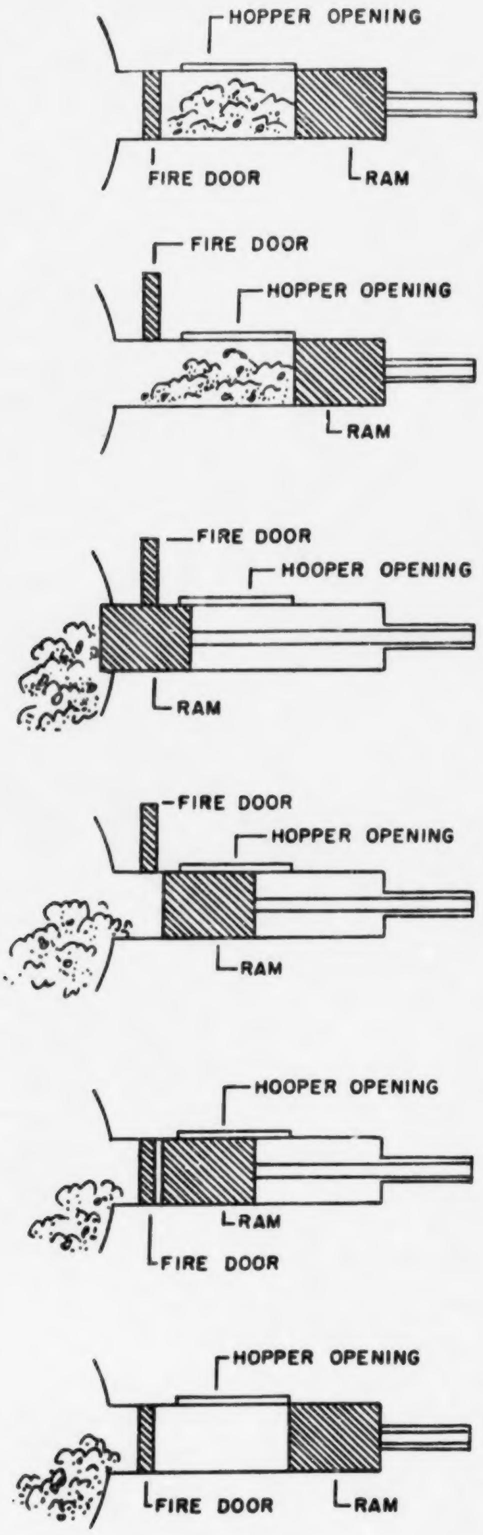
Figure 4. MUNICIPAL INCINERATOR MODULE

ORLANDO, FLORIDA


HEAT DUMPING STACK
NORMAL EXHAUST
STEAM SEPARATION
STACK LINING: CASTABLE REFRACTORY
GAS DIVERTER SECTION
RECOVERY SECTION
DUAL FUEL BURNER (2,000,000 BTU/HR)
POLLUTION CONTROL CHAMBER
PRIMARY CHAMBER (550 CU. FT.) LINING: FIRE BRICK LOWER SECTION CASTABLE REFRACTORY UPPER SECTION.
FULL OPENING DOME REFRACTORY LINED
AUTOMATIC LOADER (REMOTELY CONTROLLED)
INSPECTION DOOR
RAM FEEDER
ASH REMOVAL PAD
DUAL FUEL BURNER (2) FOR OIL OR GAS (900,000 BTU/HR)
BLOWER
HYDRAULIC UNIT

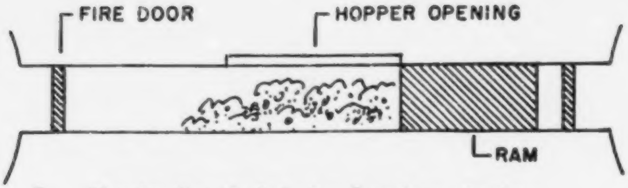
MUNICIPAL INCINERATOR MODULE
SILOAM SPRINGS, ARKANSAS

Figure 5.

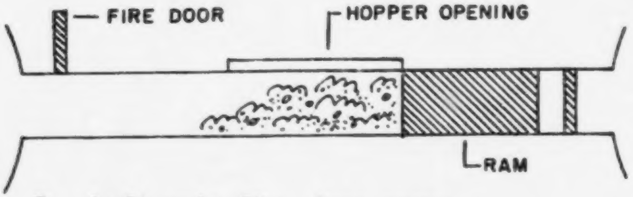

HOPPER OPENING
FIRE DOOR
RAM
FIRE DOOR
HOPPER OPENING
RAM
FIRE DOOR
HOOPER OPENING
RAM
FIRE DOOR
HOPPER OPENING
RAM
HOOPER OPENING
RAM
FIRE DOOR
HOPPER OPENING
FIRE DOOR
RAM

1. Waste loaded into loader chute.
2. Fire door opens.
3. Ram comes forward.
4. Ram reverses to clear fire door.
5. Fire door closes.
6. Ram returns to start position.

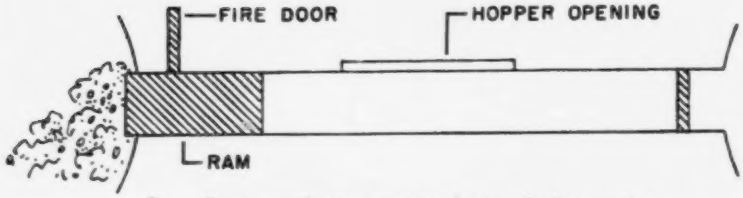
Figure 6. AUTOMATIC LOADING SYSTEM, PAHOKEE, AND SILOAM SPRINGS


FIRE DOOR
HOPPER OPENING
RAM

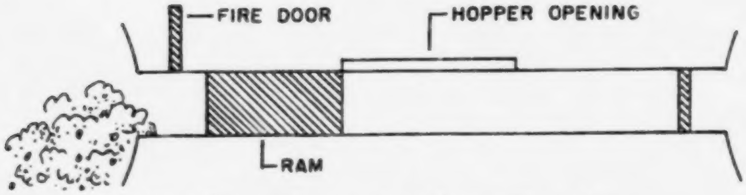
1. Waste loaded into loader chute.


FIRE DOOR
HOPPER OPENING
RAM

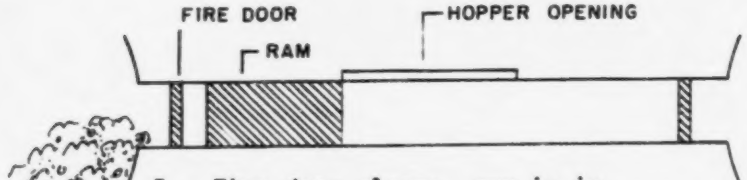
2. Left unit fire door opens.


FIRE DOOR
HOPPER OPENING
RAM

3. Ram pushes waste into left unit.


FIRE DOOR
HOPPER OPENING
RAM

4. Ram returns to clear fire door.


FIRE DOOR
RAM
HOPPER OPENING

5. Fire door closes, ram is in position for charging right unit.

Figure 7. AUTOMATIC LOADING SYSTEM, ORLANDO, FLORIDA

Design of Steam Production Systems

With the diminishing supplies of fossil fuels, the increasing cost of energy production, and the increasing cost of operating conventional incinerators, serious investigation commenced on the potential of using solid waste as a fuel to produce energy, in the form of steam, during the incineration process. The idea is not new. In Europe, solid waste has been used for several years as a fuel for producing steam, with varying degrees of efficiency.

One approach has been to augment fossil fuel (coal) with a percentage of the milled combustibles from the solid waste stream in firing conventional boilers for the production of steam for turbine generation of electricity. Another approach has been to convert the primary chamber of a conventional incinerator into a boiler. This is known as "waterwall incineration". Vertically arranged boiler tubes, joined by metal fins, are mounted to the refractory lining of the incinerator. Energy from the combustible segment of solid waste is absorbed by the water passing through the tubes and converts the liquid to steam. A major problem found in the process arises from the fact that conventional incinerators produce a relatively contaminated gas. The boiler tubes become coated and corroded from the chemicals and metallics in the gas stream.

We have pointed out in Chapter 2 that conventional incineration, employing excess air in the primary chamber to reduce the heat in the gases emitted during combustion, produces a much more contaminated gas than results from controlled air machines. Also, the temperature relationships are different between the two designs. To meet air pollution control codes, conventional incinerators must (or should) install mechanical, or water operated, devices to treat the emitted gases. These devices also drastically cool the gas stream. Any heat extraction for energy recovery must take place before the gas enters the pollution control devices: either in the primary chamber, or in a close-coupled secondary chamber.

The new controlled air incinerator designs are not faced with these constraints. The corrosive elements and particulates, including metallics, are considerably reduced in the gas stream by the high temperatures in the secondary chamber (after-burner), due to the use of auxiliary fuel, and without the use of mechanical pollution control devices. Hence, the energy conversion systems that have been developed for use with these incinerators have utilized the hot gas stream exiting from the after-burner chamber as the fuel to operate a packaged boiler installed adjacent to the incinerator. Theoretically, this cleaner fuel should provide more efficient and longer boiler tube life than found in conventional incinerator designs.

The controlled air incinerators installed at the Siloam Springs plant are connected to steam boilers fueled by the gases emitted from the after burners in this manner. The incinerator modules in the system are similar to those used in Pahokee and Orlando, with a primary chamber operating on reduced air and a secondary chamber operating on excess air. The difference in design is that the gases exiting from the secondary chamber can either be exhausted out the main or "dump" stack, or can be diverted through the tubes of a waste heat recovery boiler and out a secondary stack. Figure 8 illustrates the arrangement used.

By utilizing two stacks and a system of aerodynamic valving, the system is quite flexible. The flow of exhaust gases from the secondary chamber can be automatically shifted in three different directions -- up the main, or dump, stack when steam production is not desired; across, into and through the waste heat recovery boiler for steam production; or the flow can be divided between these two routes when only partial heat extraction is desired. Figure 9 illustrates this control system.

As a safety feature, in the event of a power or control failure, or excess pressure in the boiler, the gases are directed up the main stack.

Waste is charged and burned in the primary chamber in the same manner as in incinerators without the waste heat recovery feature. However, in the waste heat recovery system the controls for air and auxiliary fuel and temperature sensing are more sensitive and efficient. This results in lower gas velocities in the main chamber, a more complete oxidation process in the secondary chamber, and lower stack emissions.

Other designs using the emitted gases to heat boiler tubes in this manner have incorporated mechanical valves to direct the flow and these have experienced operational and maintenance problems from the high temperature environment. The Siloam Springs system, by using aerodynamic valving appears to have avoided this. It also has provided excellent response time, dropping from full steam production to zero in less than 10 seconds. The aerodynamic valving incorporates a jet pump design, with momentum exchange, lowering the static pressure to shift the direction of gas flow.

For such energy conversion systems to be feasible there must be a nearby customer, agreeable to buying all the steam the system will produce. The practical limit for piping steam is under one mile. Obviously, the system is more efficient if it employs a condensate return.

As waste heat recovery is performed as a substitute for burning fossil fuels in direct fired boilers, it must be economically feasible. The boiler should operate in the same efficiency range as a direct fired boiler, with auxiliary fuel consumption minimized so that there is a net savings in the use of fossil fuel over a direct fired boiler producing the equivalent amount of steam. Steam production should be continuous and of good quality.

Obviously, municipal waste is not as efficient a fuel as any of the fossil fuels - coal, oil or gas. It has a far lower Btu output per pound in its average "as received" condition and therefore greater weights must be burned to produce energy equivalent to fossil fuels. It has not the compactness of fossil fuels and, therefore, far greater volumes must be burned to produce energy equivalent to fossil fuels. The "as received" condition of municipal waste contains a high percentage of non-combustibles and a great deal of moisture, neither of which contribute to the production of heat (energy). Only the dry combustible portion can be useful in steam production.

All these factors must be considered in calculating the efficiency of a waste heat recovery system (as seen in Chapter 15). The incinerator design must be capable of accepting a wide range of waste composition, with Btu output that varies from charge to charge, and still produces satisfactory steam at the pressures and volumes required by the user. Appendix B presents the lower heating values of typical products found in municipal waste streams, and illustrates the complexity of the waste heat recovery design problem. The boiler design, the incinerator air and auxiliary fuel controls, and the combustion system must be well-engineered and well-matched if the boiler efficiency is to be comparable to direct fired units using fossil fuels.

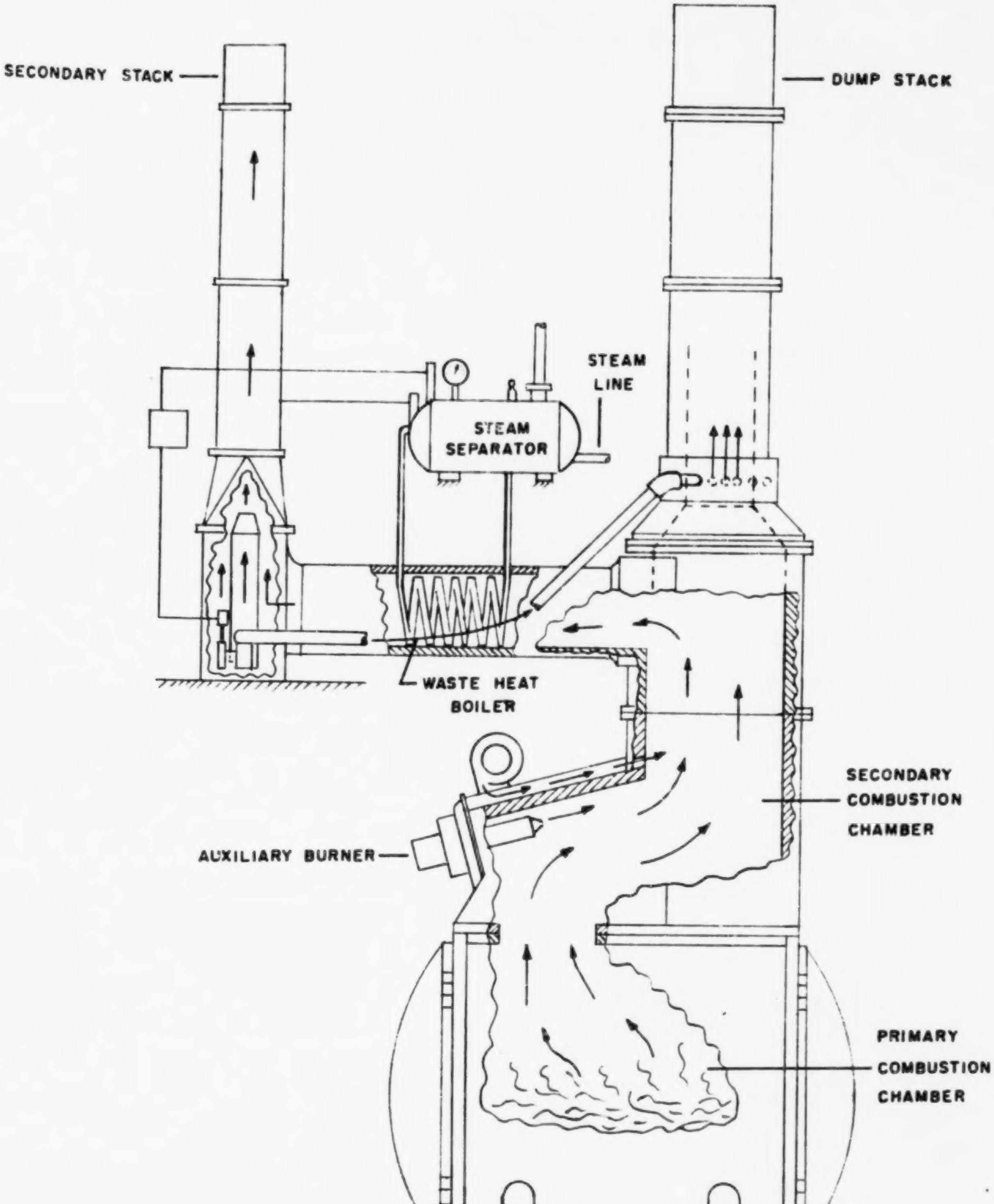

SECONDARY STACK
DUMP STACK
STEAM LINE
STEAM SEPARATOR
WASTE HEAT BOILER
SECONDARY COMBUSTION CHAMBER
AUXILIARY BURNER
PRIMARY COMBUSTION CHAMBER

Figure 8. GAS FLOW IN STEAM PRODUCTION SYSTEM
SILOAM SPRINGS, ARKANSAS

Figure 9 shows how the waste heat energy system operates. Two stacks are provided to give the system a wide range of operational flexibility. The large stack is used to operate the equipment as an incinerator only. The smaller stack carries the flow when the system is producing steam. Partial heat extraction can be maintained by dividing the flow. This flow control is maintained by a patented aerodynamic valving arrangement.

In the event of a power failure or control failure the system will immediately direct the hot gases through the dump stack. Once the incinerator is operating, this rapid response feature will control the system from full steam production to zero in less than ten seconds. This results in capital savings by eliminating the need for a condenser or other heat dissipating device.

The aerodynamic valving also eliminates the need for mechanical valving in either stack, reducing maintenance costs.

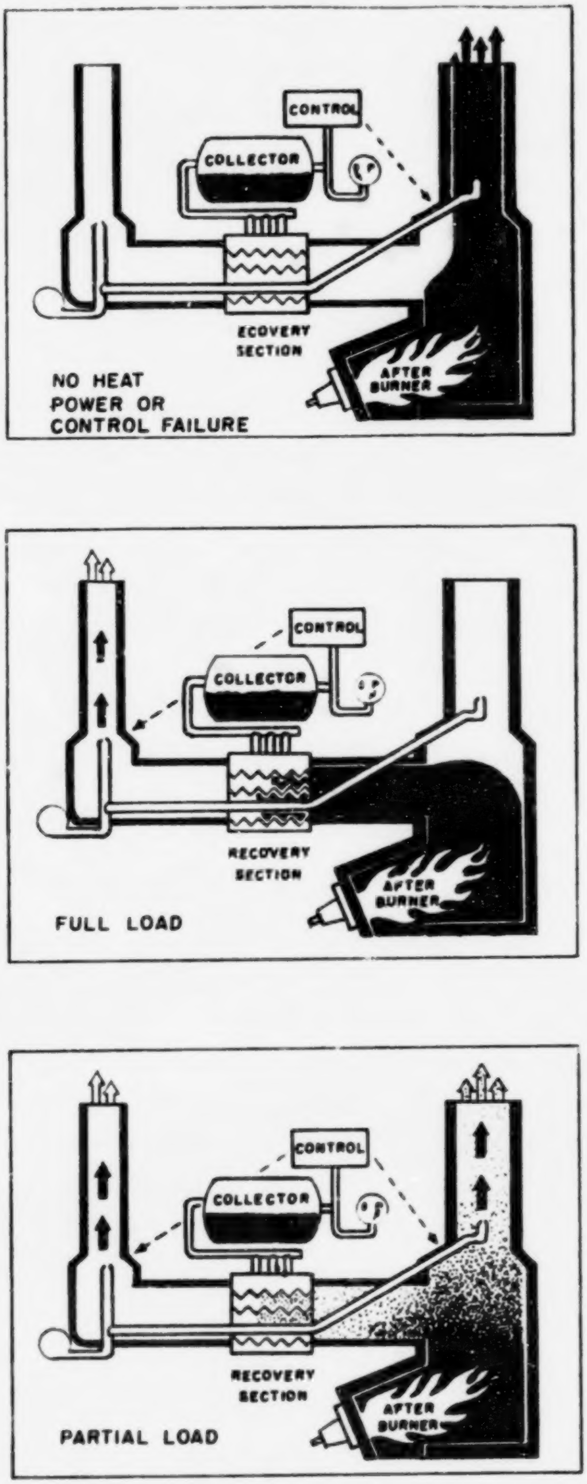

CONTROL
COLLECTOR
ECOVERY SECTION
AFTER BURNER
NO HEAT POWER OR CONTROL FAILURE
CONTROL
COLLECTOR
RECOVERY SECTION
AFTER BURNER
FULL LOAD
CONTROL
COLLECTOR
RECOVERY SECTION
AFTER BURNER
PARTIAL LOAD

Figure 9. CONTROL SYSTEM FOR GAS FLOW
SILOAM SPRINGS, ARKANSAS

Design of Plant and Buildings

The general engineering design of all the plants surveyed was fairly similar. They consisted of steel prefabricated buildings, raised approximately six feet from ground level, with the interior floor a concrete flat slab, sloped to floor drains to permit high pressure hosing and other good housekeeping practices. In each case, the building is approached by the waste trucks from a drive-in entrance, with a ramp of approximately 10 degrees leading from the driveway and into the building.

The waste is deposited, by truck loads, on the plant floor, adjacent to the loading platforms that lead to the incinerator charging boxes. The incinerator modules are mounted on concrete pads and on a lower level to permit the loading vehicles to scoop and push the waste from the plant floor onto the loading platform and allow full front bucket loads to drop into the receiving boxes of the automatic ram chargers.

The Pahokee and Siloam Springs plant buildings are square and the two incinerators are placed at the end of the building opposite the truck entrance. The plants are rated 17 tons and 21 tons, respectively, per 10 hour day. (See Figures 10 and 11 and photographs on pages 39 to 43). The 100 ton plant at Orlando consists of eight furnaces. The building is a rectangular structure 120-ft. by 180-ft. Four modules are located, in pairs, with common loaders between them, on each of two sides of the building. (See Figure 12 and photographs on pages 45 to 46). In this plant the waste trucks drive through the building and exit the opposite side.

As can be seen from the photographs on page 42, the addition of the waste heat recovery boilers to produce steam at the Siloam Springs plant resulted in a modified architectural design of the building. At the other two sites the incinerators are set on open pads with no roof, or other protection from the weather around them. At Siloam Springs, the incinerators are completely enclosed to protect them and the steam boiler equipment from the weather; the stacks protrude through the roof. Large overhead doors are cut into the building at each side to match the ash removal doors of the incinerators.

It would appear that enclosing the incinerators offers an improvement in plant design, preventing weathering of metal shells and reducing maintenance costs.

The steam boilers are above the level of the secondary chamber, elevated about 12 feet above the plant floor. This is accomplished in the Siloam Springs plant by installing a welded steel balcony over the incinerators to hold the boilers, together with all accessory equipment, such as feed water storage tank and steam separator, water conditioner, air compressor and tank for boiler tube blow down, and the various gauges and control panels.

Each plant contains an office, washroom facility and storage area to hold tools, spare parts and maintenance supplies.

In each case, the plants are located on plots that are fenced, attractively landscaped and are well maintained.

At Orlando and Pahokee the residue is carried to and spread on a plot on the plant site. At Siloam Springs, it is hauled to the municipal landfill.

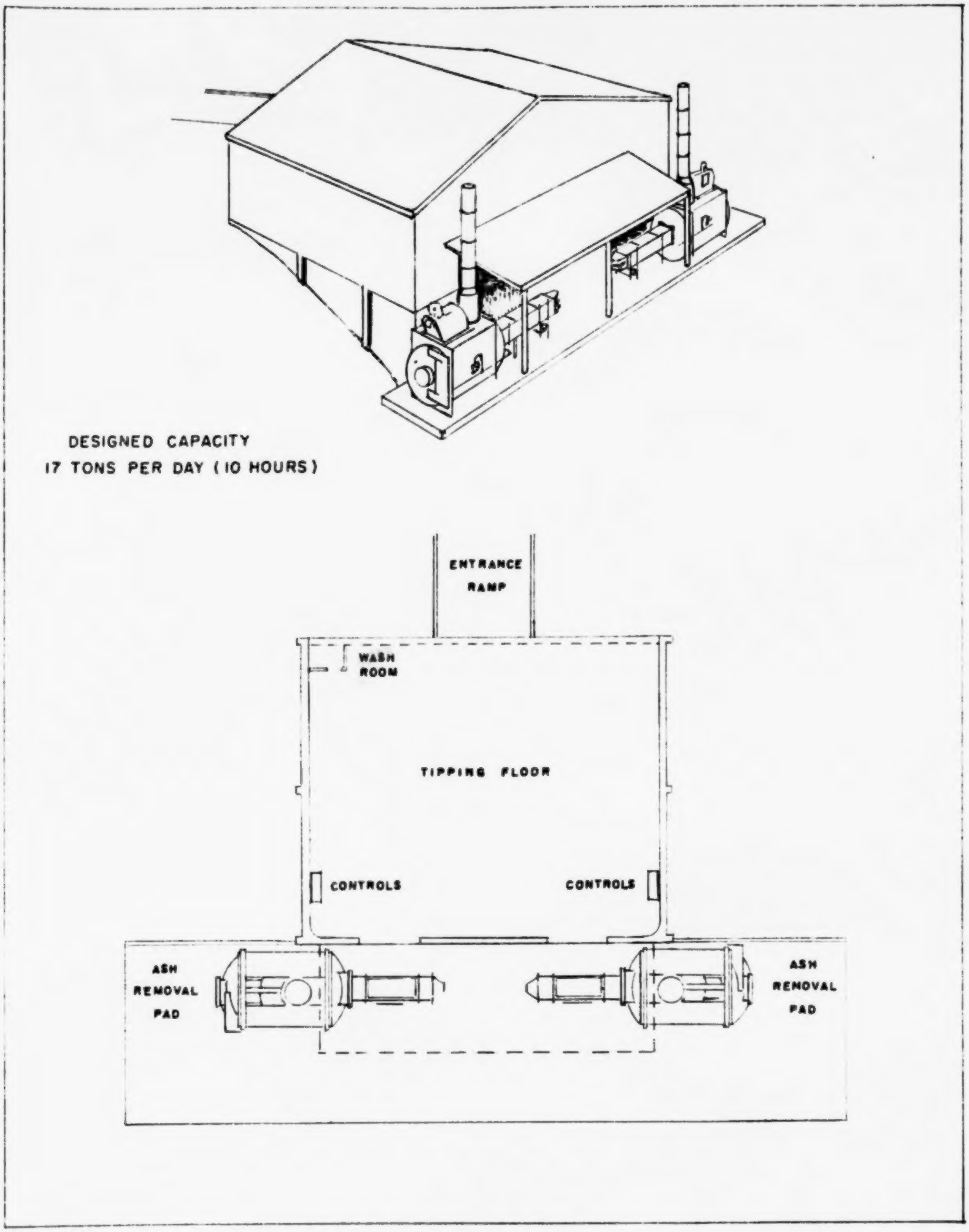
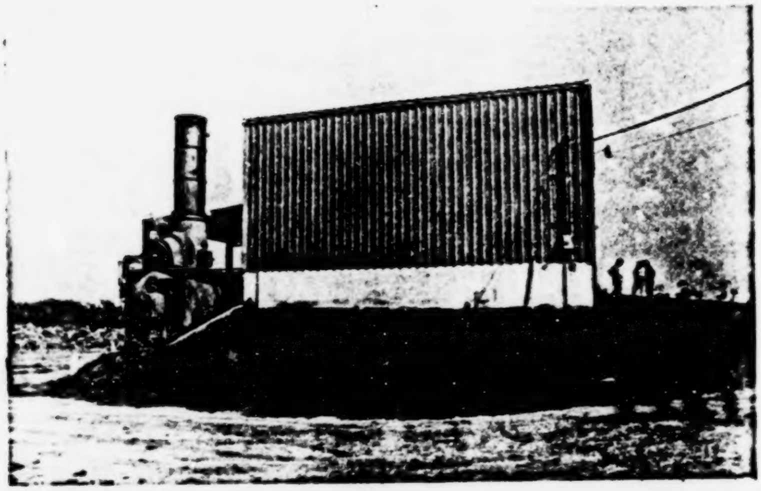

DESIGNED CAPACITY
17 TONS PER DAY (10 HOURS)
ENTRANCE RAMP
WASH ROOM
TIPPING FLOOR
CONTROLS
CONTROLS
ASH REMOVAL PAD
ASH REMOVAL PAD

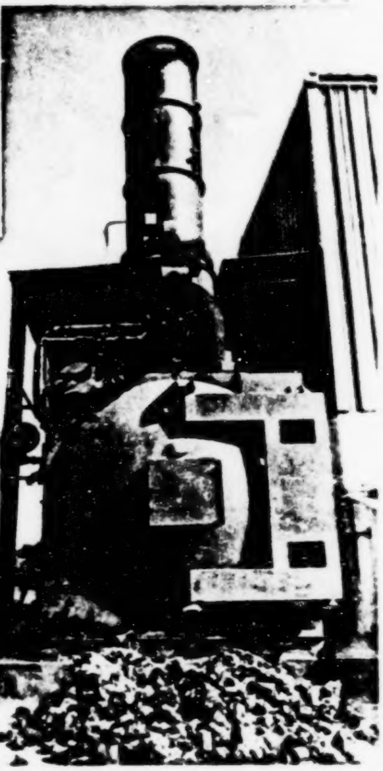
Figure 10

MUNICIPAL INCINERATOR PLANT

PAHOKEE, FLORIDA



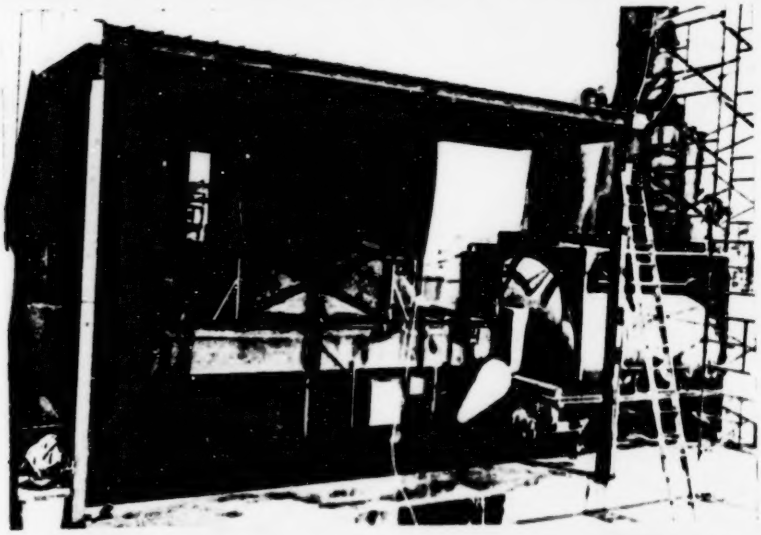
Pahokee, Florida has a plant rated at 17 tons per 10 hour day. It is constructed from a prefabricated building, raised above ground level on a concrete slab, which forms the flat tipping floor for the waste deliveries by the compactor trucks.



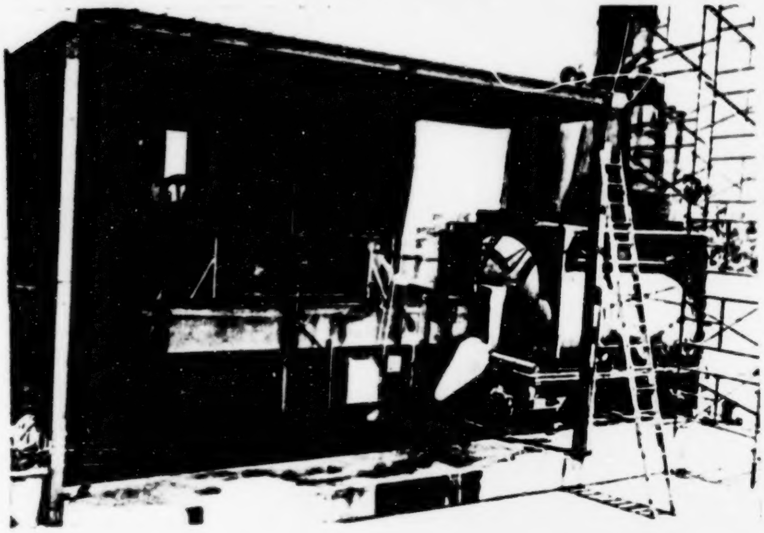
Pahokee is typical of the design of modular small incinerator plants servicing communities of under 10,000 population. The two 8.5 ton per day incinerators are installed on pads at the rear of the building below the level of the plant floor to permit gravity loading of the charging hoppers.

Photograph 1
PAHOKEE, FLORIDA

A front loading tractor alternates the charges to the incinerators at a rate of one to each unit every eight minutes. Scooped from the waste pile on the tipping floor, a load is pushed to the entrance chute platform, from which it drops into the hopper and is ram fed into the incinerator.



The hopper cover opens to receive the waste when the driver activates a pendant switch hanging in the doorway to the loading platform.



As the driver backs into the plant floor, he activates a second switch, which closes the hopper cover and energizes the ram that charges the load into the incinerator.

Photograph 2
PAHOKEE, FLORIDA

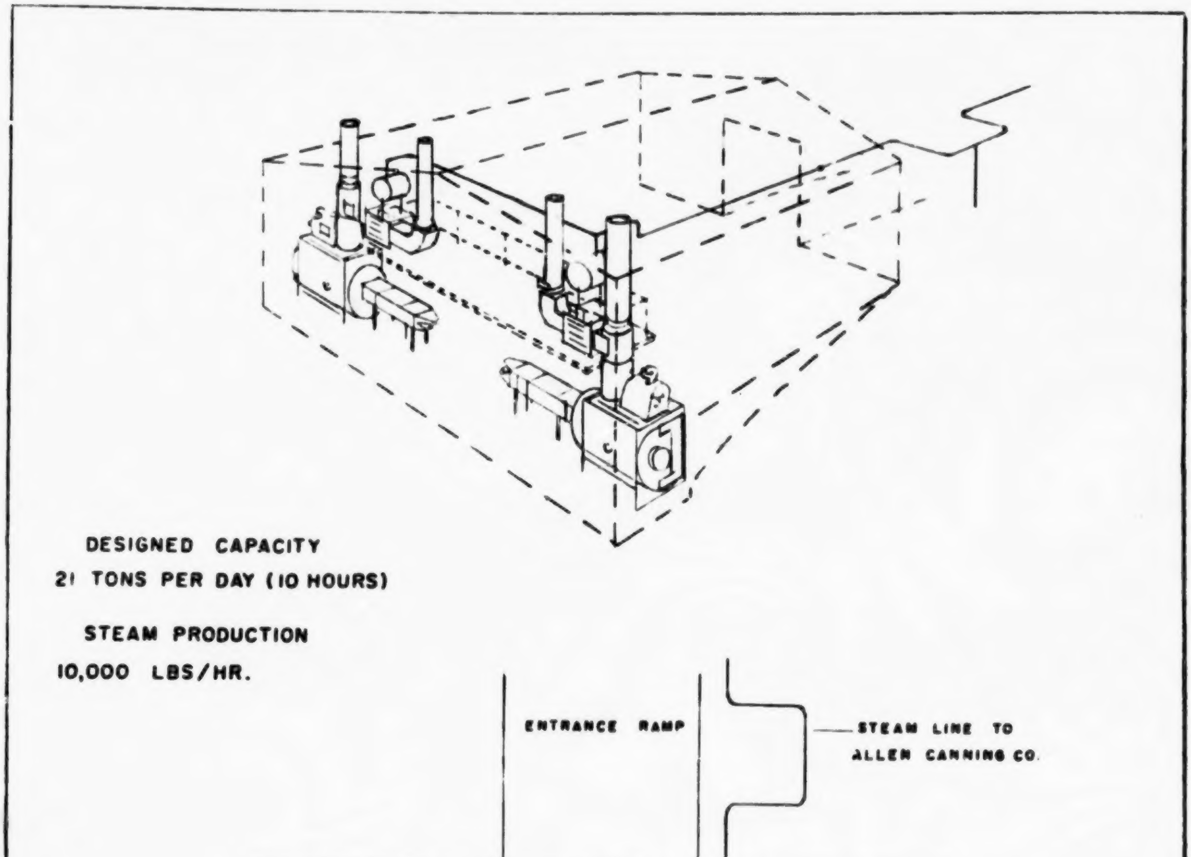
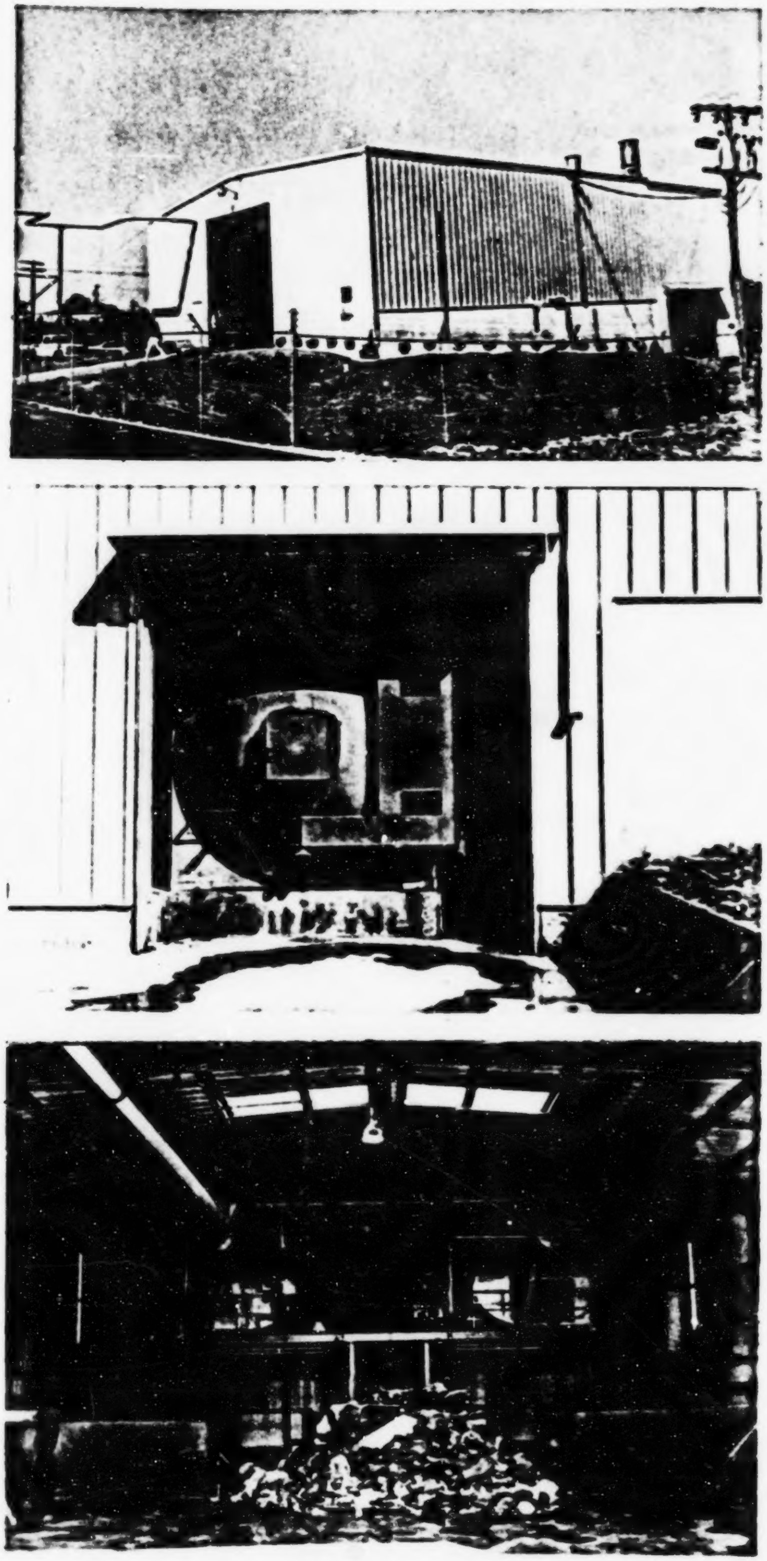

DESIGNED CAPACITY
21 TONS PER DAY (10 HOURS)
STEAM PRODUCTION
10,000 LBS/HR.
ENTRANCE RAMP
STEAM LINE TO ALLEN CANNING CO.
OFFICE
TOIL
STORE ROOM
TIPPING FLOOR
CONTROLS
CONTROLS
BALCONY & STEAM BOILERS
ASH REMOVAL PAD
ASH REMOVAL PAD

Figure 11

MUNICIPAL INCINERATOR PLANT WITH STEAM BOILER
SILOAM SPRINGS, ARKANSAS.



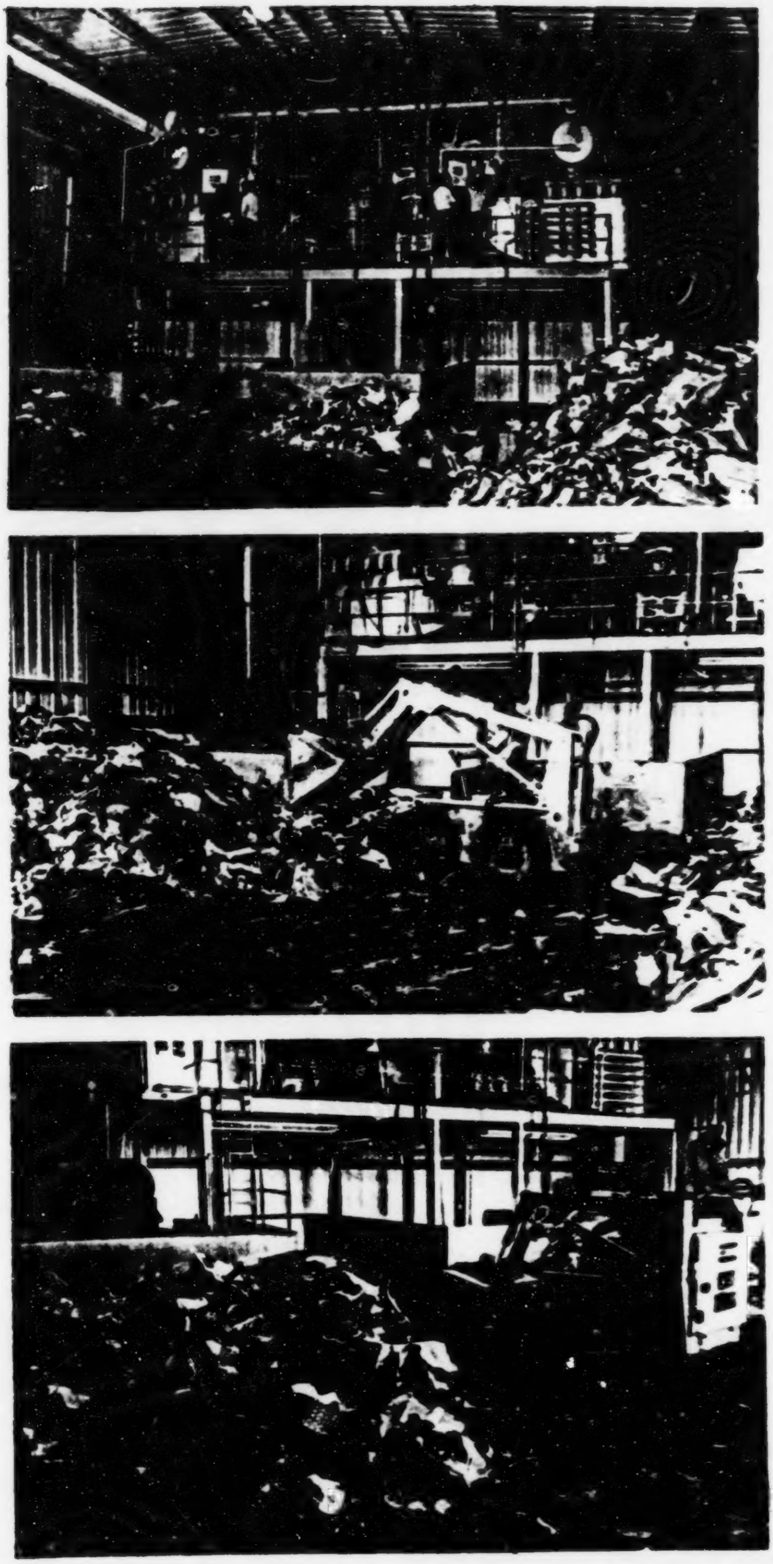
Siloam Springs has installed a 21 ton per day plant. Energy recovery from incinerating the municipal waste produces steam at the rate of 100,000 pounds daily.

The photograph shows the insulated steam line as it exits the front of the building. The canning company that purchases the steam is located directly across the street.

In this plant both of the 10.5 ton per day incinerators are enclosed by the building. Large overhead doors permit complete opening of the units for ash removal.

Steam production equipment is installed on a balcony above and between the two incinerators.

Photograph 3
SILOAM SPRINGS,ARKANSAS



When the gases from the secondary chamber are diverted through the waste heat boiler they enter at around 1800°F and exit at less than 350°F. The steam is generated in excess of 100 psig and at a rate of 5,000 pounds per hour from each boiler. This equals the production of an in-house boiler at the canning plant. The average efficiency of the waste heat boiler is 70%.

A front loading tractor feeds the two incinerators at Siloam Springs.

Photograph 4
SILOAM SPRINGS, ARKANSAS

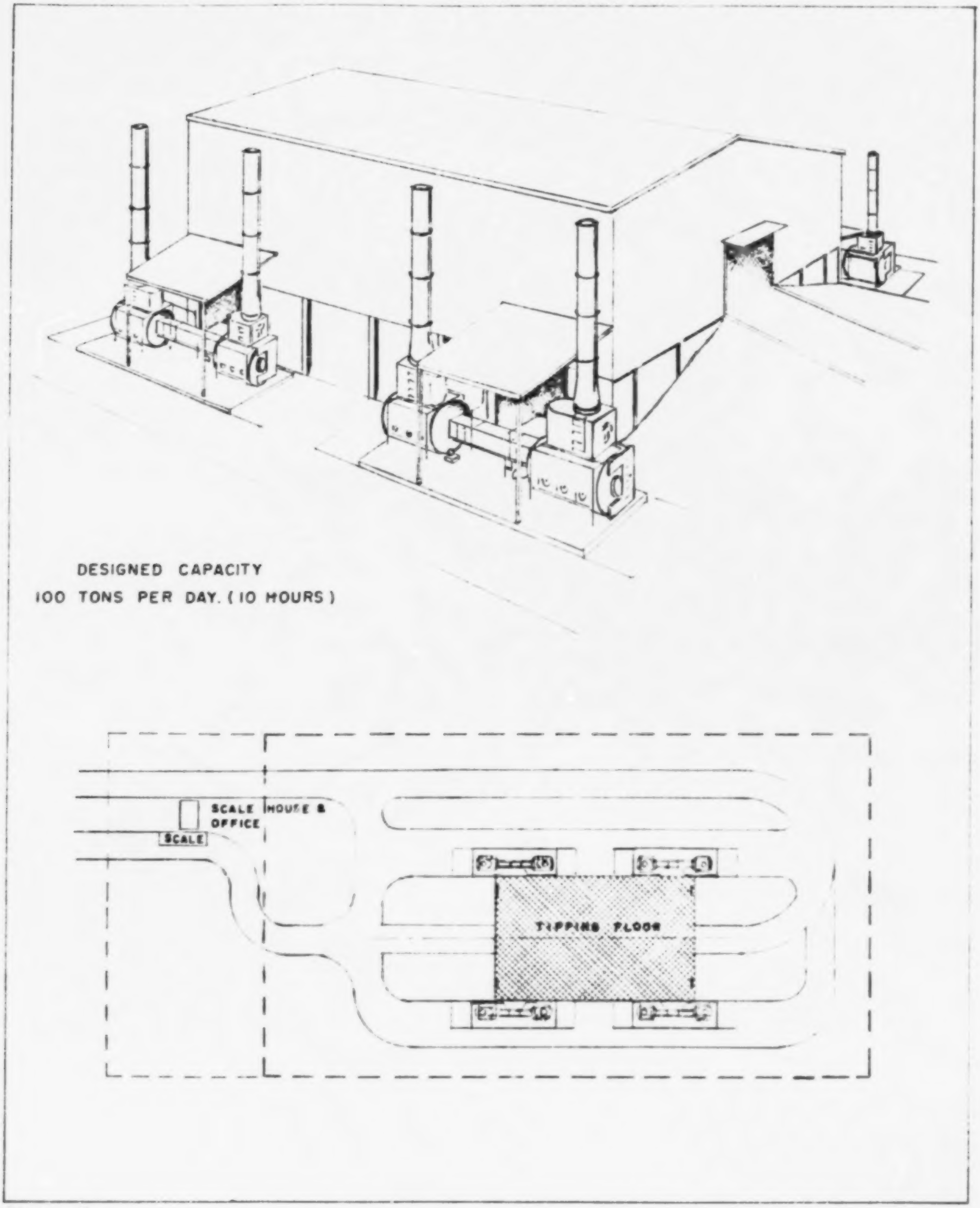
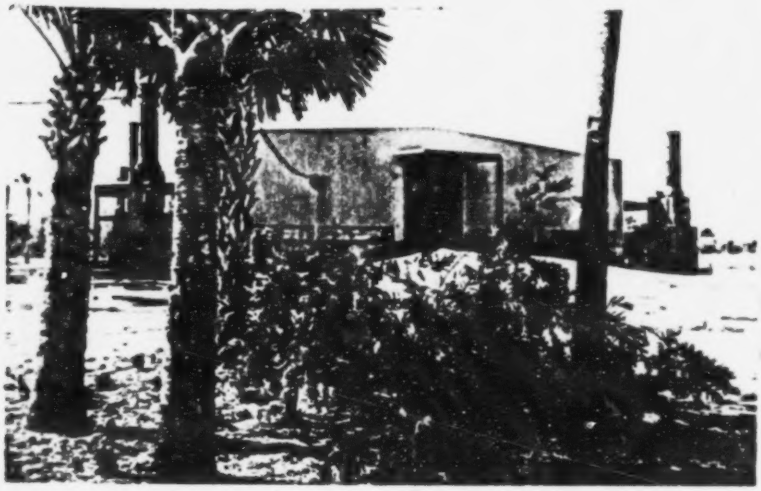

DESIGNED CAPACITY
100 TONS PER DAY. (10 HOURS)
SCALE HOUSE & OFFICE
SCALE
TIPPING FLOOR

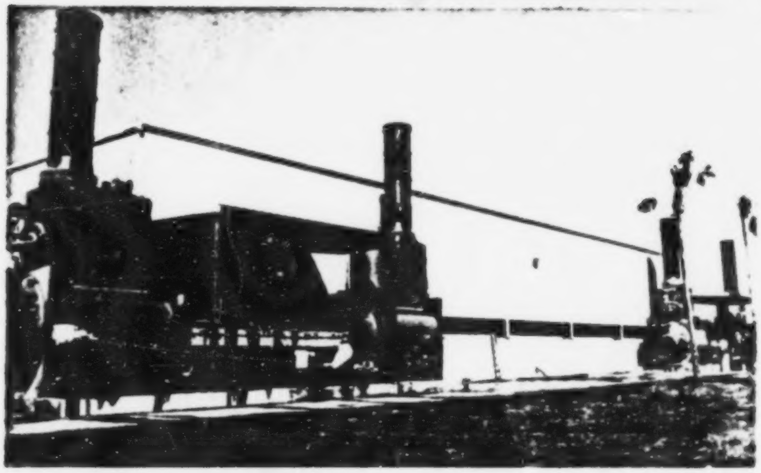
Figure 12

Mc LEOD RD. MUNICIPAL INCINERATOR PLANT.

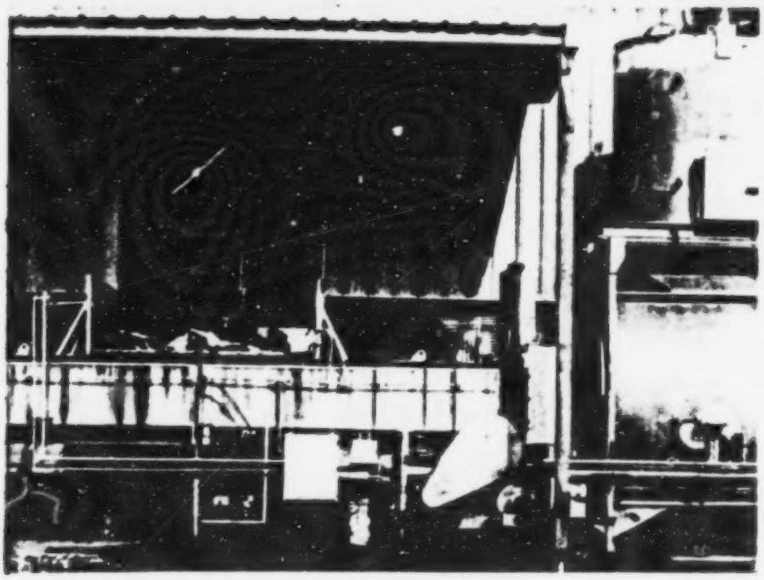
ORLANDO, FLORIDA



The 100 ton per day plant at Orlando, Florida is typical of the larger modular municipal incinerators. It handles one quarter of the waste generated by this 120,000 population community.

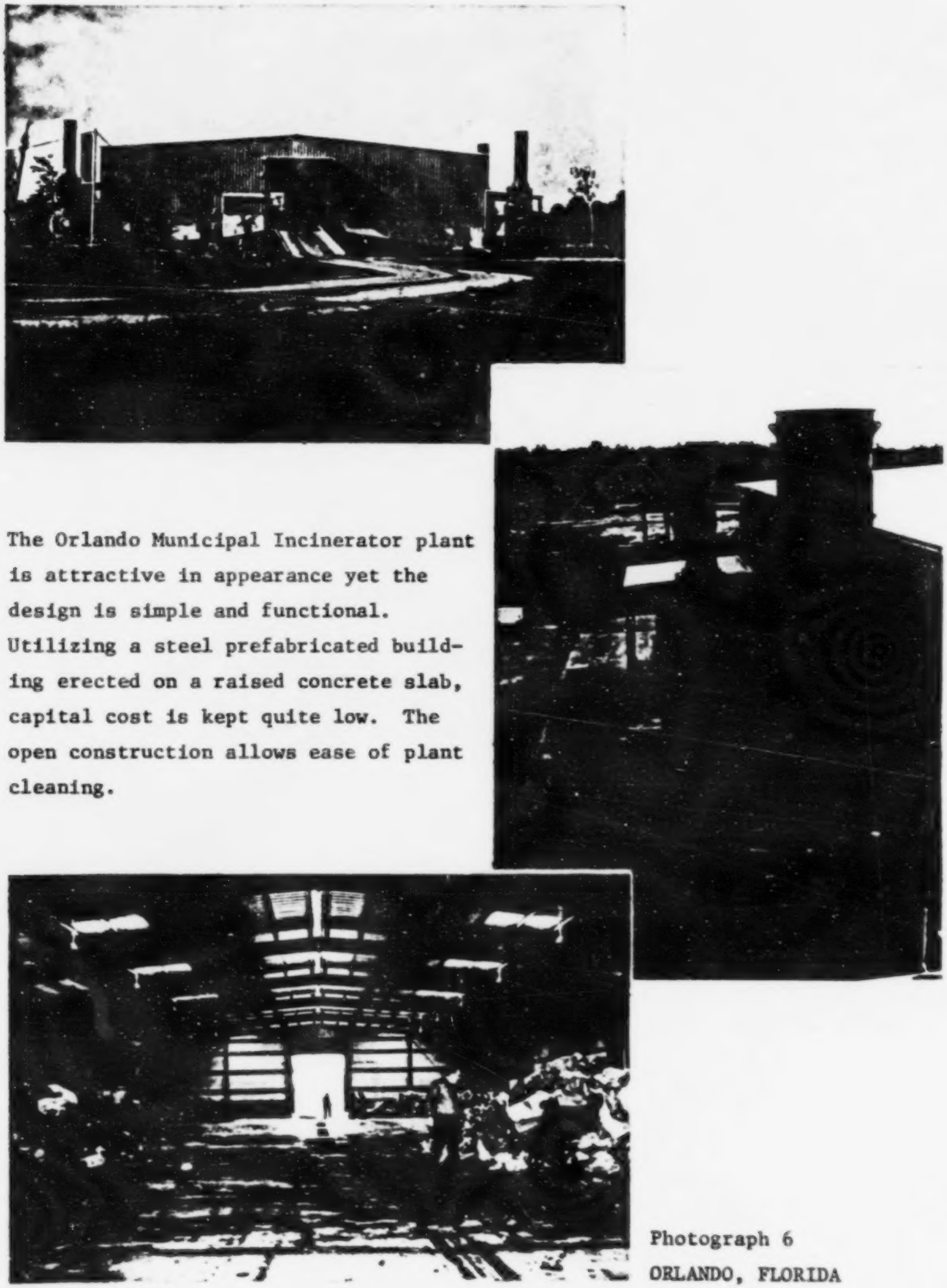


The construction and landscaping ensure that good community relations are maintained. The plant is attractive and clean, with environmental problems eliminated.



The incinerators are installed in pairs on the periphery of the building. A common loader charges each pair.

Photograph 5
ORLANDO, FLORIDA



The Orlando Municipal Incinerator plant is attractive in appearance yet the design is simple and functional. Utilizing a steel prefabricated building erected on a raised concrete slab, capital cost is kept quite low. The open construction allows ease of plant cleaning.

Photograph 6
ORLANDO, FLORIDA

CHAPTER 5

PLANT OPERATION SYSTEMS

Each plant uses similar systems for receiving waste, charging the incinerators and removing the ash residue. The main differences between plants are in their capacities, in architectural design and in staffing patterns utilized.

Orlando is the only one of the three plants that has its own truck scale, with automatic recorder-printer and scale house. Admittedly, this is not an inexpensive accessory for a municipal plant. However, the use of a scale is the only satisfactory method for maintaining an accurate record of the net weights of waste and burned each day. Without such daily records it is nearly impossible for the plant owners to determine the efficiency of a plant, as virtually all calculations must tie into the weight of waste handled and the ash residue removed. Further, if charges to customers are based on weight of waste received, a weigh scale is essential.

Orlando, as the largest capacity plant, has the largest staff - plant supervisor, secretary-bookkeeper, shed foreman, four tractor operators, a skilled laborer and a laborer who is also the residue truck driver - a total of nine. Siloam Springs utilizes a combination plant supervisor-boiler operator and two laborers. Pahokee employs a plant supervisor and a laborer and pays for part of the Public Works Director's salary to cover office assistance.

Compared to the large incinerator plants these would appear to be large labor forces for the tonnage of waste handled. However, as the plants are not automated for sorting, shredding or charging the waste into the loading hoppers, these appear to be the minimum labor figures to permit efficient daily operation and maintenance.

The bulk of the waste is delivered onto the plant tipping floor in compactor trucks and dumped into piles adjacent to each loading platform that leads to the charging box of an incinerator. At Orlando this normally is placed into four piles, each feeding two incinerators that have a common charging box and reciprocating ram between them. At the other two plants both machines are normally fed by a single pile placed between them.

The normal operation is for a tractor operator, using the front loader, to scoop a full load of waste from a pile and push it onto the loading platform. When the pile on the platform is approximately three hundred pounds in weight (roughly a cubic yard in size) the tractor operator energizes a pendant mounted push button switch to open the door of the charging box, pushes the entire load off the end of the loading platform, dropping it into the charging box. As he backs out of the platform he pushes another switch in the pendant that closes the feed box door and activates the ram mechanism.

The charging is normally signalled for by the incinerators themselves, based on their heat sensing, and a red light calling for a charge. On an average, depending on the model, each machine is charged from six to eight times per hour. The operator alternates his charges between two units.

The incinerators are normally charged from seven to ten hours per day. They then continue to burn down for approximately three hours more, at which point they cool down until the next morning.

Ash residue removal takes place as soon as each plant opens in the morning and is done by one operator using a tractor with a long ash "rake" attached to the front end. After the module has been emptied onto the ash platforms in front of it, it is then ready for the day's burning operation. After a few minutes cooling time the tractor operator removes the ash from each platform, either by front loader or into a dump truck. Should it be determined that the ash requires further cooling before hauling, water is sprayed on it by an ordinary garden hose.

Once the incinerators have come up to heat, solid waste that has already been dumped on the plant floor is charged into each incinerator unit.

The floor of the shed is kept clean by hosing it down constantly, and at the end of the day, the entire plant is swept and hosed down. As a result of excellent housekeeping practices, there is little odor in any of the plants.

The flow diagrams in Figure 13, 14 and 15 show the difference in systems design at each plant.

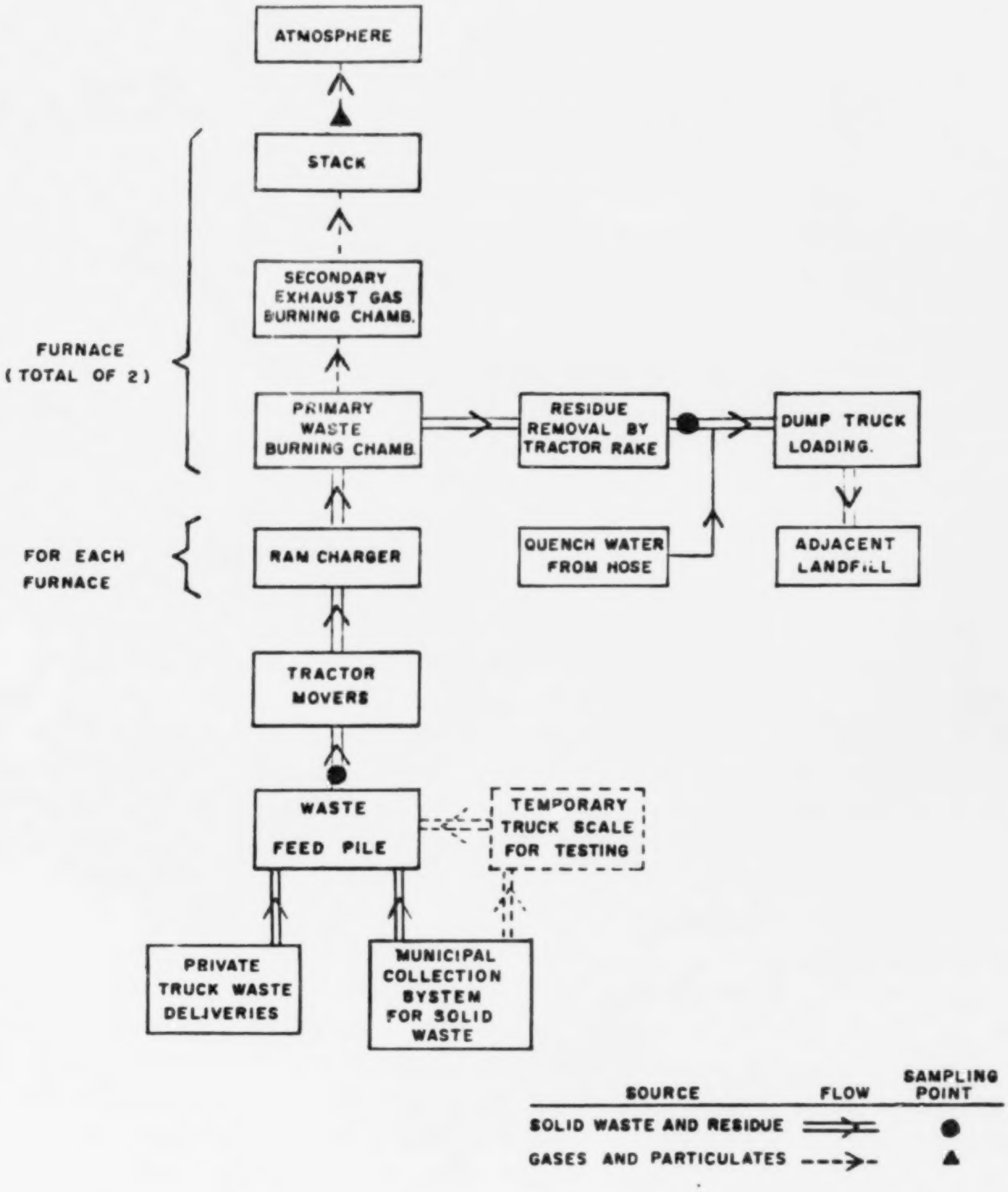

ATMOSPHERE
STACK
SECONDARY EXHAUST GAS BURNING CHAMB.
FURNACE (TOTAL OF 2)
PRIMARY WASTE BURNING CHAMB.
RESIDUE REMOVAL BY TRACTOR RAKE
DUMP TRUCK LOADING.
FOR EACH FURNACE
RAM CHARGER
QUENCH WATER FROM HOSE
ADJACENT LANDFILL
TRACTOR MOVERS
WASTE FEED PILE
TEMPORARY TRUCK SCALE FOR TESTING
PRIVATE TRUCK WASTE DELIVERIES
MUNICIPAL COLLECTION SYSTEM FOR SOLID WASTE
SOURCE
FLOW
SAMPLING POINT
SOLID WASTE AND RESIDUE
GASES AND PARTICULATES

Figure 13.

FLOW DIAGRAM FOR PAHOKEE MUNICIPAL INCINERATOR

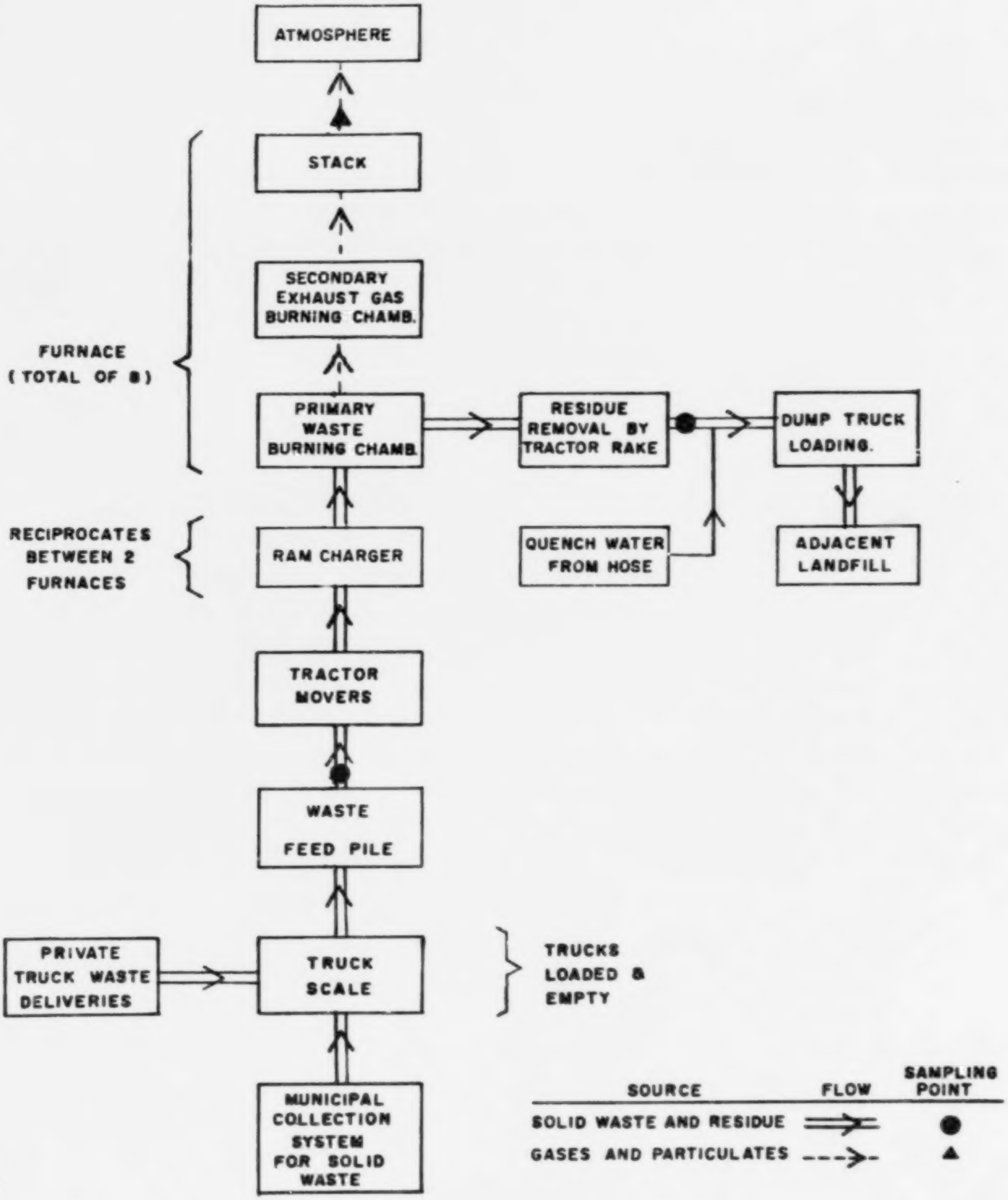
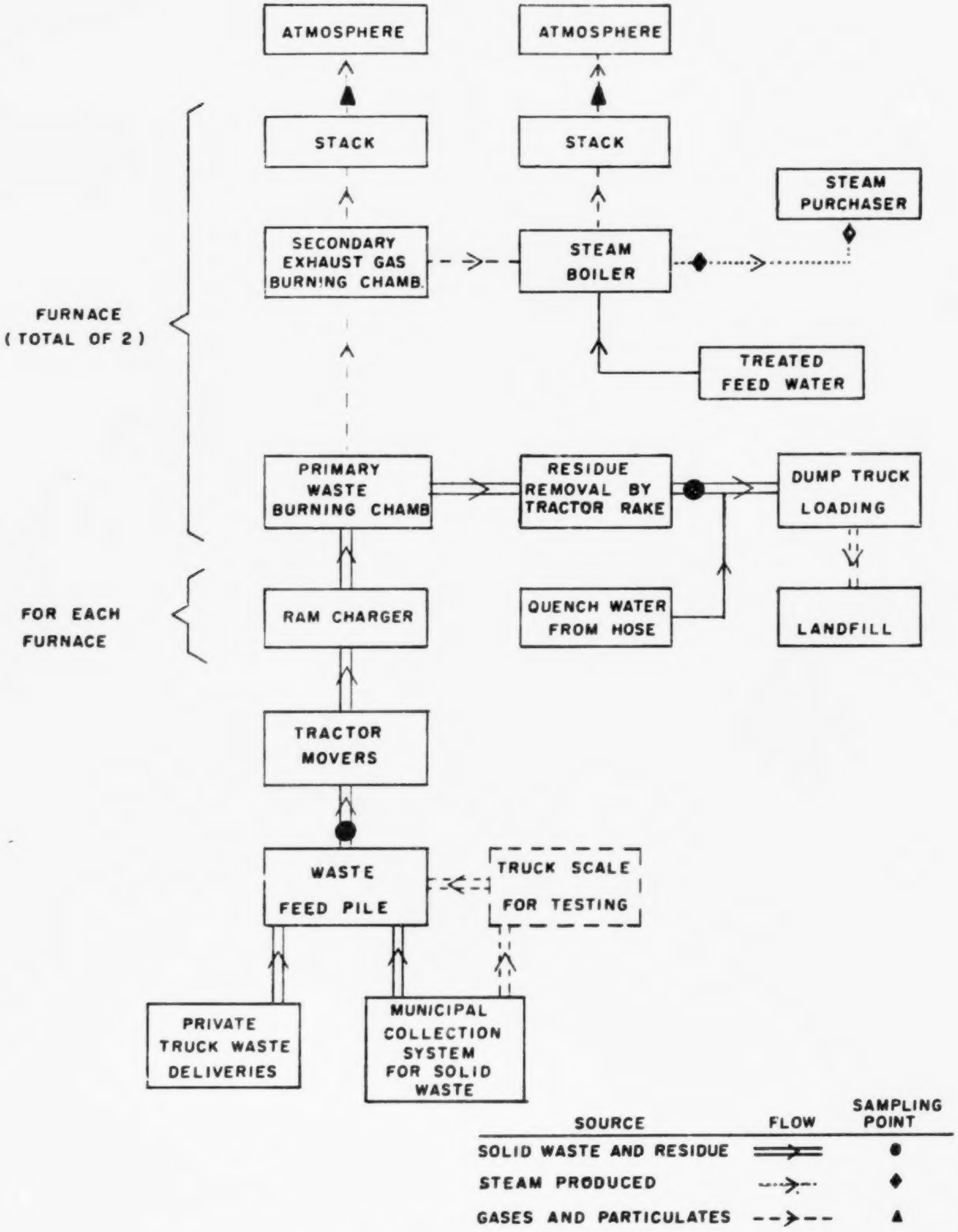

ATMOSPHERE
STACK
SECONDARY EXHAUST GAS BURNING CHAMB.
FURNACE (TOTAL OF 8)
PRIMARY WASTE BURNING CHAMB.
RESIDUE REMOVAL BY TRACTOR RAKE
DUMP TRUCK LOADING.
RECIPROCATES BETWEEN 2 FURNACES
RAM CHARGER
QUENCH WATER FROM HOSE
ADJACENT LANDFILL
TRACTOR MOVERS
WASTE FEED PILE
PRIVATE TRUCK WASTE DELIVERIES
TRUCK SCALE
TRUCKS LOADED & EMPTY
MUNICIPAL COLLECTION SYSTEM FOR SOLID WASTE
SOURCE
FLOW
SAMPLING POINT
SOLID WASTE AND RESIDUE
GASES AND PARTICULATES

Figure 14.

FLOW DIAGRAM FOR ORLANDO MUNICIPAL INCINERATOR


ATMOSPHERE
ATMOSPHERE
STACK
STACK
STEAM PURCHASER
SECONDARY EXHAUST GAS BURNING CHAMB.
STEAM BOILER
FURNACE (TOTAL OF 2)
TREATED FEED WATER
PRIMARY WASTE BURNING CHAMB
RESIDUE REMOVAL BY TRACTOR RAKE
DUMP TRUCK LOADING
FOR EACH FURNACE
RAM CHARGER
QUENCH WATER FROM HOSE
LANDFILL
TRACTOR MOVERS
WASTE FEED PILE
TRUCK SCALE FOR TESTING
PRIVATE TRUCK WASTE DELIVERIES
MUNICIPAL COLLECTION SYSTEM FOR SOLID WASTE
SOURCE
FLOW
SAMPLING POINT
SOLID WASTE AND RESIDUE
STEAM PRODUCED
GASES AND PARTICULATES

FLOW DIAGRAM FOR SILOAM SPRINGS MUNICIPAL INCINERATOR

Figure 15.

CHAPTER 6

THE TESTING PROTOCOL

The testing and evaluation of any incinerator system is done with the following objectives in mind:

1. To determine the efficiency of the incinerator system as a solid waste reduction device, in terms of the volume and weight of the waste processed in the system and the residue remaining
2. To determine the pollution load released to the environment, in terms of the quality and quantity of gaseous, solid and liquid effluents released during incineration.
3. To determine the operating, maintenance, ownership, and financing costs.
4. To determine the limitations of the system in terms of processing the solid waste stream that is normally delivered; to completely characterize its operation on a day-to-day basis; and to evaluate the effects of the system's design, as well as operational variations, on its intended performance.
5. To characterize the "as received" solid waste to determine the moisture and Btu content.
6. In the case of small incinerators of the controlled air design, to monitor the use of auxiliary fuel and consumption of power.
7. Where the system incorporates waste heat recovery through steam production, to determine the efficiency of the design and its economic feasibility.

The majority of the work in such testing can be performed at the incinerator site followed by laboratory analysis of samples. This means a logistic plan for testing prepared well in advance of the test period; with the installation of instrumentation, measuring devices, weighing devices, and the utilization of plant space in a manner that permits accurate testing with as little interference as possible to the normal day-to-day operation of the plant. It also infers that the plant management has maintained adequate and accurate records involving such matters as fuel and utility consumption, capital and operating costs, incoming waste weights, reduction efficiencies, residue weights and volumes and other operating criteria, for a sustained period before the test and evaluation period takes place. This will permit comparisons and correlations between the data found during the test period and the long run data maintained by plant management.

Any incinerator plant is a mass production installation and space is normally at a premium. For a testing situation, conditions are not always ideal. Occasionally, compromises will have to be made, but they should always be considered and carefully studied to ensure that they do not overly influence the findings. Therefore, successful testing can be performed only with cooperation from the plant management. For example, if the plant lacks scales, or bulk measuring devices, or good capacity materials handling devices for evaluating raw waste and residues, they must be brought to the plant and used on a temporary basis during the testing period to ensure adequate data is collected.

The EPA Testing Manual for Solid Waste Incinerators describes the types of procedures, protocols and tests that should be followed in testing and evaluating any incinerator -- municipal, industrial, commercial or institutional installation.

Preliminary Test Arrangements

s Preliminary visits were made by the evaluation team to each incinerator plant approximately six weeks before the testing period to ensure that all necessary logistical arrangements were completed well before actual testing began. During these preliminary surveys the following information was obtained.

1. Normal burning schedules, charging rates, weighing procedures, cycles of operation, and related operational data.
2. Physical characteristics of the plant, such as solid waste storage provisions, charging method, pollution abatement equipment and residue handling equipment.
3. Sampling locations for solid waste, residue, and exhaust gases as well as steam production.

4. Location and size of stack sampling ports and the scaffolding requirements for performing stack sampling. Stack modification was not required for any of the sites tested.

5. Types, location, and form of readout of plant instrumentation. Arrangements were made to have these instruments calibrated, if necessary, before the study began and to install additional fuel meters to record fuel usages. Each plant had kept records of these instrument readings, and arrangements were made to obtain the readings for the months preceding the study period.

6. Availability of electricity (type and location of outlets, quantity of power, voltage, size of circuit breakers or fuses, etc.) and water.

7. Location of economic data and names of personnel to contact regarding this data.

8. Types and meanings of all alarm signals and appropriate action to take should an alarm sound.

9. Types and composition of auxiliary fuel, and analytical data regarding the fuel.

10. Names and telephone numbers of personnel connected with the management and/or operation of the plant, such as Director of Public Works, superintendent, foremen, etc.

11. Any available data from previous studies of the incinerator such as burning rates, emission rates, and efficiency.

12. Determination of the total auxiliary fuel consumption, firing rate, and burning time periods, including burn-down and cooling period.

13. Drawings of the incinerator, design data, and both theoretical and actual performance data.

The study team then notified the Office of Solid Waste Management Programs in writing 30 days prior to the test that this data had been assembled to allow an Office representative to be present as an observer at each test. Mutually convenient test dates were established.

Charging and Operation

During the test period the incinerators were charged and operated in the same manner as they would be for normal day-to-day operation. The tests were conducted while burning the same type of waste normally burned in the incinerator.

Determination of Charging Rate

The determination of charging rate during stack testing and also during the entire study was measured, rather than estimated. Measurements were used in order to relate weight of waste charged to stack emission data and to calculate efficiency and material balance.

Several alternatives are offered by the EPA Testing Manual. The selected method consisted of setting aside each day during the study a quantity of waste of known weight sufficient to sustain operations for a one day charging period, charging in the normal manner and rate; noting the time each charge is placed in the loading hopper, as well as noting the total burning time for this waste.

To determine average weights both charged and burned per hour, during the entire study, the total weight of waste charged to the test incinerator each day (and that was set aside for the specific test incinerator) was recorded.

The total charging time for the day, as well as total burning time, was recorded. From this was calculated the average weights charged and burned per hour. The total number of charges was also recorded from which the average weight of each charge was calculated.

The procedure at each plant was identical. As each truck load was weighed, it was then dumped on the flat plant floor adjacent to the test incinerator and kept entirely separate from all other waste delivered to the plant. Loading of the incinerator was performed by a tractor, with a front loader. This machine scooped waste from the test pile and shoved it into the loading hopper of the incinerator from which it was ram charged into the primary burning chamber. This operation continued until the entire test load had been charged. A record was maintained of the exact time of day for each load that was charged into the ram operated hopper of the test incinerator.

Operational Data

In order to identify the variables encountered in the plant operation, data pertaining to the operation was obtained during the test period. This data was acquired through the use of specially prepared survey forms which are illustrated in Appendix "A". The study team worked closely with the operator of the unit during the testing period. An operating log was maintained in which all changes and adjustments in operation were noted, along with the reasons for such changes.

Instrumentation Monitoring

From the monitoring instruments with which the plants were equipped, fuel, heat, and steam readings were recorded at hourly intervals during the active test period, utilizing additional survey forms included in Appendix "A". This data was used as an aid to identifying existing operating conditions and any deviations from normal. The log commenced on the day of the trial run to determine operating characteristics of the facility, and continued during all active testing until the tests were completed.

Physical Composition Determination

The burning rates, heat release, stack gas effluents and residue characteristics are directly affected by the character of the incoming raw waste. The moisture content of the raw waste can range from 15 percent to 50 percent or more. Heat content of the "as received" waste can vary from below 3,000 Btu/pound to over 10,000 Btu per pound. Some loads can contain as much as 30 percent non-combustibles in glass and metal while other loads can be as small as five percent. Considerable testing has shown great differences between residential and so-called commercial and industrial wastes. For these reasons, it is essential in testing incinerators to know fairly accurately the makeup of the raw waste being burned; both on a bulk basis and by testing representative samples in a laboratory.

Considerable statistical analyses have been performed in the past to determine the composition of the "typical" waste being burned each day and, therefore, the character of the total waste being processed by a particular plant.

Past efforts have shown that waste piles on an open plant floor can be visually inspected fairly easily and, through the use of a grab sample (selecting a certain area of the solid waste pile) 200 to 300 pound typical samples for that particular pile can be extracted for determining the physical and chemical composition of the waste. This procedure was used by the study team for the three plants tested. Tests on large incinerators in the mid-1960's established the validity of using the "small" 200 to 300 pound samples (as compared to "large" samples weighing as much as 1,700 pounds), providing the grab samples were representative of the total waste based on appearance.

Particulate Emission Testing

Since the passage of The Clean Air Act of 1970 and the promulgation of new source performance standards for incinerators burning 50 tons or more per day, emission test procedures have been standardized and the definition of particulate matter set for compliance purposes with Federal Standards. Test procedures that were used in the present study conform to "Standards of Performance for New Stationary Sources", Office of Air Programs, Methods 1 - 5, issued by the Environmental Protection Agency as published in the December 23, 1971 issue of the Federal Register. The detailed methodology used during the testing period was based on the *"Testing Manual for Solid Waste Incinerators"*, U. S. Environmental Protection Agency, 1973. By using a standard test protocol at all three plants, the data becomes comparable between the three in every detail.

The modular municipal incinerators at Pahokee and Orlando, Florida, and Siloam Springs, Arkansas, do not come under the law as stated in the Federal Register, since the individual furnaces burn less than 50 tons of waste per day. The criteria applying to units of 50 tons per day and over were followed in order to provide a comparison with larger capacity municipal incinerators. Local codes may differ from this and may differ depending on the capacity of an incinerator. They should always be consulted when planning for, or purchasing, any incinerator, or in setting up testing protocols.

Particulate emissions are defined as the "dry catch", or that part of the sample collected on or before the filter in the sample train (See Fig. 16, Pg. 76). Some states still consider the "condensable catch" in the determination of compliance with state and local codes. "Condensable catch" is defined as those solids remaining behind after a careful evaporation of an aloquat of the impinger water at conditions near ambient temperature and low relative humidity. "Total catch" is the addition of the dry catch and condensable catch.

Data reduction and computations were done by computer using equations and formulas specified in the standard test procedures and those additional equations and formulas necessary for the handling of the data.

When the preliminary, or trial runs are considered, four complete test runs were conducted at each test site. Standard test procedures and equipment were used, and no modifications were necessary.

The specific incinerator units selected for testing were chosen at random from those installed at each plant, and the manufacturer's cooperation was solicited in assuring that the units were in proper repair. The units in each case were operated according to the manufacturers' recommended standard practice. Charging rates during the test period were established near the design rate. At no time during any testing were conditions encountered that could be described as abnormal or upset.

Daily Monitoring Schedule

The logistics of efficient testing of any incineration plant involve following a rather fixed schedule to ensure that testing or monitoring is performed efficiently. Hence, well in advance of testing the first site, a Daily Monitoring Schedule was drawn up, to ensure that the testing procedures used at all three sites were identical and thus comparable. Table 1 illustrates this schedule. The collection forms used in the field are included in Appendix "A".

TABLE 1

INCINERATOR PLANT MONITORING PARAMETERS

NO.	TASK	FREQUENCY
1.	Net Weight of Incoming Wastes by Truck Delivery	As delivered each day
2.	Electric Meter Reading	At start-up each day
3.	Water Meter Reading	At start-up each day
4.	Waste Charging Rate into Ram	At time of each charge
5.	Fuel Readings	Every 30 minutes
6.	Temperature - Primary Chamber	Every 30 Minutes
7.	Temperature - Secondary Chamber	Every 30 minutes
8.	Steam Production - Pressure	1 minute after each charge
9.	Steam Production - Pounds/Hour	Every 15 minutes
10.	Incoming Raw Waste Bulk Density Determination	3 to 5 times per day
11.	Incoming Waste Composition Determination	2 to 3 times per day
12.	Solid Waste Laboratory Sampling	1 time per day (random)
13.	Residue Bulk Determination	1 time at start-up each day
14.	Residue Laboratory Sampling	1 time per day
15.	Waste to Residue Reduction Calculation	1 time per day
16.	Stack Testing for Emissions, Velocity, Temperature, and Mass Flow - 4 runs per plant	48 point traverse - 3 to 5 minutes each - elapsed time at 2 1/2 to 4 hours

CHAPTER 7

WASTE LOADS AND CHARGING RATES

Waste Deliveries

The testing of an incinerator is not "real world" unless it is tested while burning the normal quantity and type of waste it handles in average daily operation. As waste was delivered by the Sanitation Department, during each of the testing days, a measured and weighed quantity was set aside for the test incinerator. This was sufficient to charge the machine for a period long enough to conduct the complete physical composition, emissions, operational and efficiency tests that have been outlined. It also permitted running the incinerator at the loading and burning rates per hour established by the manufacturer so that the capacities could be verified. Most of the calculations that must be made in evaluating an incinerator are based on knowing the exact weight of the "as received" or raw waste that is charged and burned over a given time period. In this study such weights were obtained by weighing the loaded and empty delivery trucks on certified scales. (See Form No. 1, Appendix A).

TABLE 2

DAILY WASTE LOADS CHARGED IN TEST INCINERATORS

(NET WEIGHT IN POUNDS)

Test Day	Orlando	Pahokee	Siloam Springs
1	24,500	9,780	14,420
2	27,360	15,130	16,696
3	22,940	9,830	10,640
4	25,040	12,048	
Daily Average:	24,960	11,697	13,918
Design Rates:			
10 Hour Day	25,000	17,000	21,000
Charging per Hour	2,500	1,700	2,100

As can be seen from Table 2, the waste deliveries to the Orlando units matched the design rates almost exactly. At Pahokee and Siloam Springs, the plants often do not have to operate a full day to charge the waste received, as waste generation has not yet built up to plant capacity. The average charge rate during testing was less than six tons daily against a machine capacity of 8.5 tons at Pahokee, and at Siloam Springs an average of seven tons daily against a capacity of 10.5 tons. However, both community waste loads are expanding and the plants will be approaching capacity in the near future. This under-usage registers temporarily on their economic picture, in cost per ton processed, factored against fixed operating and capital costs (see Chapter 13).

To avoid false results during testing, the waste was charged into the Pahokee and Siloam Springs incinerators at the approximate design rate. The total charging time is less than a full day as a result.

Charging and Burning Rates

With "batch type" small incinerators, the charging rate (average weight of waste charged into the unit per hour) considerably exceeds the burning rate (average weight of waste consumed during a given timeframe). Purchasers of these machines should clearly understand this when examining manufacturer's data on an incinerator's "design capacity." Unlike the large municipal conventional incinerators, the batch type units usually do not have automatic and continuous ash removal. They are designed to destroy a given weight (and, by averaging, a given volume) of waste over a 24 hour period. From this, the manufacturer develops a formula for the maximum weight (and volume) of waste to be loaded into the machine per hour for maximum efficiency of destruction and auxiliary fuel usage, and minimum emissions.

These calculations are based on a range of moisture and non-combustibles to be found in the waste and the average rate of reduction of the combustible portion. The volume of the raw waste shrinks with combustion at an average rate within an average given time period after each charge, and the residue builds up within the primary chamber at a slower and known average rate. After the last charge, auxiliary fuel remains on for an additional three hours to ensure that combustion in the primary and secondary chambers is complete. Air remains on until the unit is shut down for the next morning clean-out, to aid in cooling and final combustion.

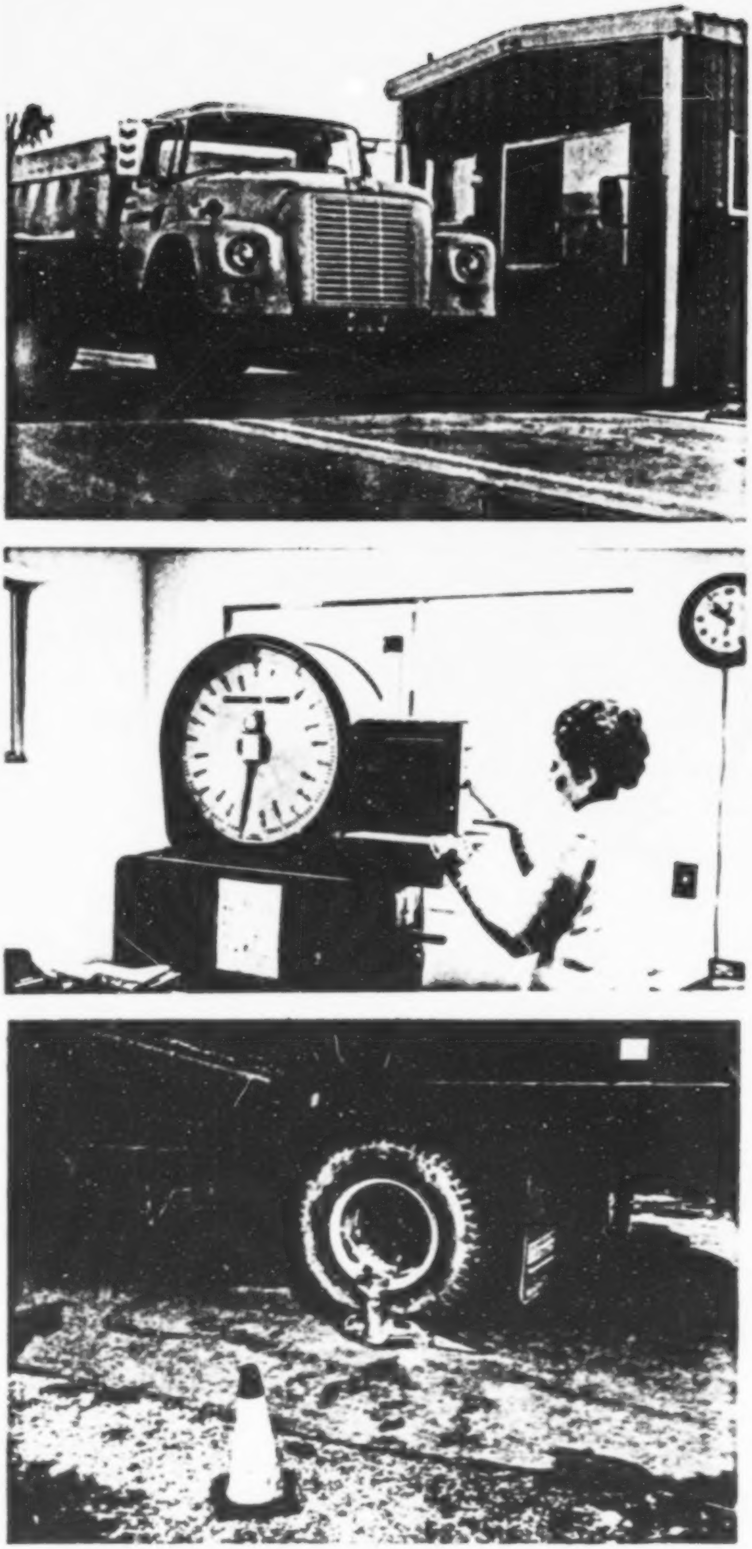
Table 3 is a summary record of the charges that were put into the incinerators during testing, showing the average number of charges per hour and their average weight, which varied as the densities of the waste varied. (Form 3, Appendix A was used to colelct this data.)

Table 3 also gives the average weight of waste "burned" per hour. This could be calculated two different ways, depending on the definition of "burning time." Combustion actually continues until there is no heat left in the waste. The "burning" period could be described as being from the time the waste was charged until the following morning, or some shorter period, when the waste has cooled. However, examination of furnace residues in incinerators of this size range have revealed that virtually all gases and the major residual heat are released within three hours after the last charge has been made. For this reason the use of auxiliary fuel is maintained for this additional three hour period. The burning time used in this report is thus the charging time plus the three hour auxiliary fuel additional burning time.

TABLE 3

DAILY CHARGING AND BURNING RATES

Plant and Test Day	Total Charge Time Hr.-Min.	Total No. Charge	Avg. No. Charges Per Hour	Total Weight Charges (Lbs.)	Avg. Wt. Per Charge (Lbs.)	Avg. Wt. Charged Per Hr. (Lbs.)	Avg. Wt. (Lbs) Burned Per Hour Using Aux. Fuel
Orlando							
1	8-18	47	5.7	24,500	521	2951	2168
2	9-34	58	6.1	27,360	472	2860	2177
3	8-52	66	7.4	22,940	348	2586	1933
4	7-56	65	8.2	25,040	385	3157	2290
Pahokee							
1	5-52	45	7.7	9,780	217	1666	1102
2	8-36	59	6.9	15,130	256	1759	1304
3	5-20	41	7.7	9,830	240	1844	1180
4	7-13	46	6.4	12,048	262	1669	1179
Siloam Springs							
1	5-49	47	8.1	14,420	307	2478	1635
2	6-59	59	8.4	16,696	283	2392	1673
3	3-58	40	10.1	10,640	266	2680	1527



All solid waste delivered to each plant for the test incinerator was recorded accurately for each daily delivery. The gross weight and tare weight of each truckload was recorded.

Where automatic printing scales were unavailable, portable scales were used.

Photograph 7
WEIGHING DELIVERIES OF
WASTE TO THE PLANTS

CHAPTER 8

INCOMING SOLID WASTE CHARACTERIZATION

Bulk Density Determination

Municipal waste often varies considerably in bulk density (weight per cubic foot) from truck load to truck load and within different sections of the waste piles that are charged into the incinerator. This has a direct correlation with burning time and thermal reduction rates and efficiency. If during testing the waste in the stream shows variations visually, the number of bulk density determinations should be increased to ensure accuracy.

Bulk density measurements of the incoming solid waste should be as accurate as conditions permit - in measuring volumes and weight. The test plants did not possess overhead cranes, or similar materials handling equipment for moving waste. Hence, all bulk density determinations had to be done by using the front loader tractors and by filling containers of a known volume and weight. The filled containers were then weighed and the net weight of waste and the bulk density calculated. (Photo 7)

The filling of the sampling containers was done without compacting the waste, to obtain accurate bulk densities of the waste "as received." The container was filled to the top, if possible, and levelled off as evenly as possible, ensuring no pockets or voids are left in corners.

Containers used for holding waste for bulk density determination were large enough to handle the large pieces found in the waste stream.

Orlando and Siloam Springs had the availability of good handling facilities and built-in scales. Bulk density samples could be taken rather simply and quickly. Based on visual examination of the received waste in the test pile, it was seen that there could be wide variations in the bulk density determinations. As a result, a total of 19 bulk density determinations were made in Orlando and 15 in Siloam Springs.

These towns provided a hydraulic front loading compactor truck with a four cubic yard removable steel container on the front end that was used exclusively for bulk density determinations. The exact tare weight of the container was obtained at the beginning of the test period. Large samples of over 1,400 pounds could be taken with the container filled level to the top. This was done approximately five times a day, weighing the filled container on the plant scales, and then depositing the waste into the truck body. Waste net weights were then calculated. The container was emptied completely after each sampling to ensure a constant tare weight. When bulk densities were completed each day, the waste that had accumulated in the dumpster truck was then deposited back into the testing pile for charging into the incinerator. (See Photograph 8).

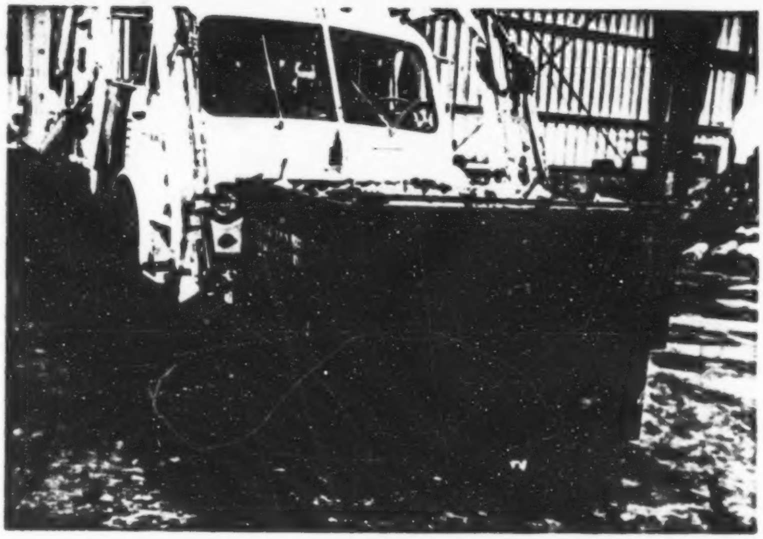
Pahokee, Florida presented a different set of conditions. Weighing had to be done on a mobile platform scale. To hold the waste, the study team constructed a two cubic yard box and, after obtaining its tare weight, placed it on the scale platform. It was then filled to a predetermined level by one of the front loading tractors, the gross weight recorded and the net weight calculated. The box then had to be emptied by hand and the waste put back into the test pile. (See Photograph 8)

Pahokee did not have the variations in bulk density of the waste as experienced in Orlando. This could be seen from visual examination of the waste pile. As a consequence, only eight bulk density determinations were made over the four day test period.

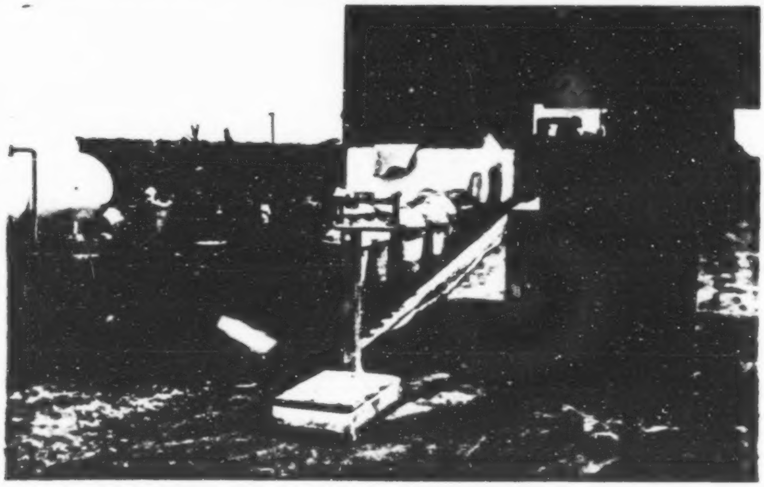
Table 4 gives the bulk density determinations of each sample tested at each site. While the waste at Pahokee and Siloam Springs was fairly consistent, it will be noted that Orlando's waste showed extreme fluctuations in density, due to the type of waste generated. This was influenced by the collection day and source from which it was collected, resulting in entire loads of commercial versus residential waste being delivered. The difference in the density of the two types is clearly shown in Table 4. The residential waste ranged from 10.6 to 24.4 (average 13.2) pounds per cubic foot. The commercial waste ranged from 5.3 to 9.1 (average 6.9) pounds per cubic foot. This illustrates the importance of weighing sufficient samples to adequately measure the variations in density of waste sources and thus characterize the peaks and valleys of density that an incinerator will have to handle.

Table 4 also illustrates the differences in waste streams between municipalities. Table 5 shows some of the causes of density variation; paper and plastic have low density; garden waste and non-combustibles have the highest. In short, between communities it is difficult to define an "average" municipal waste.

Various methods were used by the study team to obtain the bulk densities of the raw waste.



When material handling equipment was available, large steel bins of a pre-recorded tare weight and volume were used; filled completely, they were moved by compactor trucks and weighed on truck scales to permit calculation of total weight of large volumes of waste.



When such equipment was unavailable, portable scales and a hand operation were used.

Photograph 8
BULK DENSITY
DETERMINATION

TABLE 4

BULK DENSITY OF RAW WASTE SAMPLES

(POUNDS PER CUBIC FOOT)

Sample No.	Orlando	Pahokee	Siloam Springs
1	17.5	10.9	8.7
2	15.3	9.7	9.1
3	24.4	9.2	5.1
4	10.6	8.9	8.6
5	10.6	12.1	8.0
6	12.8	13.9	11.4
7	12.6	11.2	9.7
8	6.9	11.6	7.8
9	5.8		8.2
10	13.3		6.7
11	6.0		8.0
12	9.1		4.8
13	9.0		8.6
14	6.4		8.5
15	5.3		4.6
16	12.4		
17	11.1		
18	14.4		
19	14.8		
Average all samples	11.5	10.9	7.9

Physical Composition Determination

Sampling to determine physical composition of the raw waste at the three small incinerator plants was accomplished by spreading a large plastic sheet on a level concrete floor. A tractor load of approximately 200 pounds of waste was dropped on the plastic sheet. Twenty-gallon plastic containers weighing between four and five pounds and marked both with tare weight and by various waste categories were placed around the periphery of the plastic sheet. These categories were: food waste; garden waste; paper products; plastic, rubber and leather; textiles; wood; and fines; glass and ceramics; and ash, dirt and rocks. Two technicians manually sorted the raw waste samples into the 20-gallon containers. Any waste material whose composition fell into more than one of these components was placed into the component where the vast majority of its weight fell. Once the samples had been sorted, they were weighed on a beam scale of 50 pound capacity and accurate to one ounce. The tare weight of the containers was subtracted from the gross weight, giving the net weight of each component. (See Photograph 9)

Statistical analysis reveals how many samples should be taken during a test period to achieve reasonable accuracy in dividing the waste and determining the percentages of makeup by any particular component. For example, if a particular component by visual inspection amounted to 50 percent of the total waste, a total of eight samples must be separated to obtain a precision of 10 percent of the mean for this component. The precision of the components which constitute a small proportion of the total sample must by necessity be sacrificed in order to keep the number of samples required within practical limits. Eight samples taken over a five day testing period appear to be a good compromise between precision and practicality. The number of samples should be statistically divided as evenly as possible over the number of days of the study period. When more than one sample is taken per day, the sample should be spread throughout the day (morning and afternoon).

This procedure was followed closely in the present study. Samples were taken each morning and each afternoon during the four day study period at each site to determine the characteristics of the daily waste piles.

Table 5 shows the physical composition of the raw waste charged to each of the different test incinerators. These were the average of all samples assembled at each location. These were considerable differences between the communities, which are believe to arise from a combination of socio-economic factors. It must be emphasized that spot checks made before the present study indicates these waste makeups have been fairly typical over a prolonged period at each site.

TABLE 5

AVERAGE PHYSICAL COMPOSITION OF INCOMING RAW WASTE

(PERCENTAGE BY WEIGHT)

Category or Component	Orlando	Pahokee	Siloam Springs
COMBUSTIBLES - Total	83.0	72.6	74.5
Food Waste	5.0	26.8	11.0
Garden Waste	20.2	.6	3.7
Paper Products	45.3	30.7	48.4
Plastics, Rubber, Leather	5.0	7.2	10.5
Textiles	3.9	6.8	.5
Wood	3.6	.5	.4
NON-COMBUSTIBLES - Total	17.0	27.4	25.5
Metals	5.6	5.7	13.2
Glass, Ceramics	9.5	21.4	12.1
Ash, Dirt, Rocks	1.9	.3	2
TOTAL	100.0	100.0	100.0

By-Pass Wastes

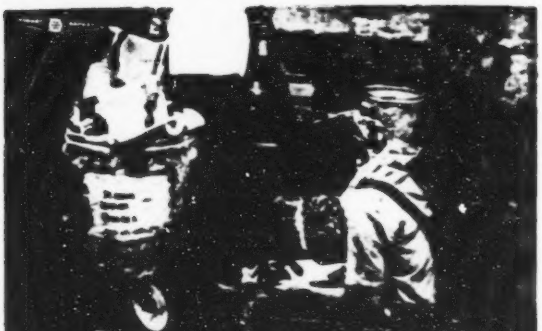
Every morning, before and during charging, tractor drivers and plant workers spot check waste piles. Wastes such as bicycles, propane containers, and garden wastes over four feet long and four inches in diameter, or any objects that plant employees find to be too large or otherwise incompatible with incinerating equipment, are set aside and transported to the nearby landfill.

Pahokee generates virtually no by-pass wastes, except for the occasional broken appliance or automobile part. Orlando, representing a more affluent society, generates by-pass wastes as high as 300 pounds per day, ranging from appliances, toys, automotive parts to bicycles and furniture. Siloam Springs has a fairly carefully controlled waste pick-up system and hence by-pass wastes are almost non-existent.

Separation of the waste to determine its composition was done at all test sites. Grab samples of around 200 pounds in weight were divided into their nine major components.

The components were weighed in waste cans to an accuracy of one ounce. 20 pound laboratory samples were prepared to the same weight percentages as the large grab samples.

Photograph 9
SEPARATION OF INCOMING WASTE



CHAPTER 9

RESIDUE CHARACTERIZATION

The incinerators did not have automatic ash removal systems. Each utilized a final burn-down and cooling period from approximately eight in the evening until seven in the morning. This meant the ash residue was relatively cool when removed and quenching water was used sparingly from a garden hose before hauling the residue to the landfill.

It was decided to weigh the complete residue of the test incinerator each morning in a container of a known tare weight and volume. The simplest approach was to load the residue into a pre-weighed dump truck, with prerecorded dimensions of the bed. The residue could be levelled off and measured on the truck scales and the net weight and bulk density of residue calculated.

This procedure was followed at each plant and performed first thing each morning. By comparing the volume and weight of residue with the total volume and weight of raw waste charged the previous day the reduction efficiency for the entire load was calculated. For details on the reduction during each test, see Chapter 12.

Visual examination of the residue to determine the amount of non-combustibles in the waste as well as the completeness of reduction of the combustibles is an interesting exercise, but cannot be substituted for laboratory analysis. When it is realized that each test incinerator burned from 5 to 13 tons of waste per test day, and reduced the raw waste weight by approximately 70% and the volume by over 90%, the appearance of the residue could easily give false clues as to the incinerator efficiency.

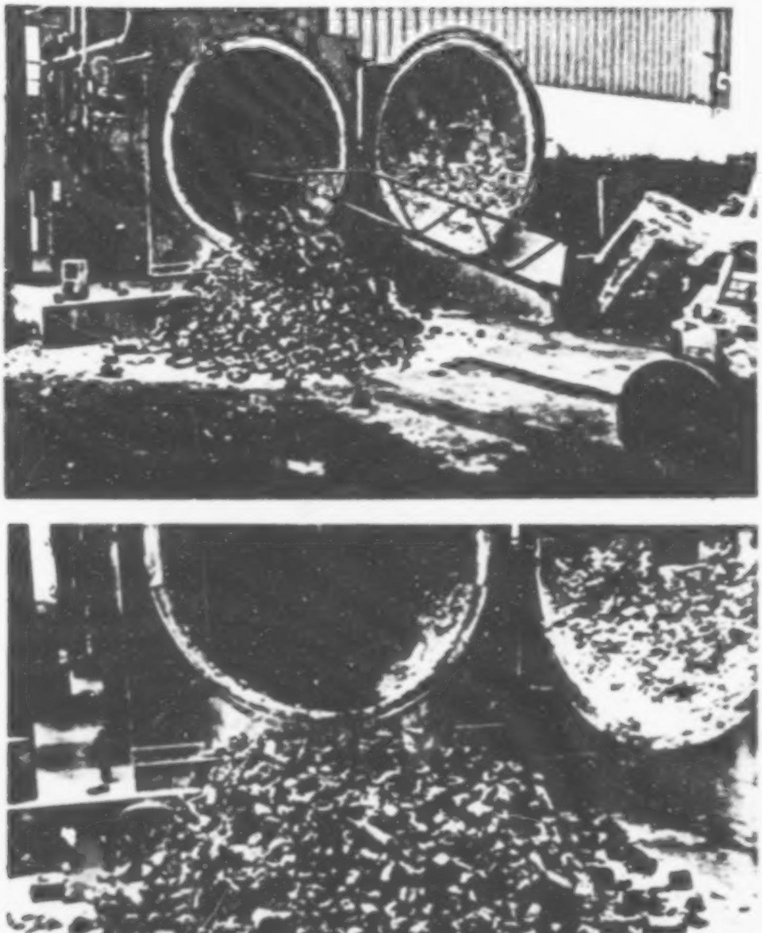
Metal cans are probably the element that stands out the closest to the original form and most of these virtually disintegrate when handled. Glass appears to melt into large "clinkers", which cause problems in residue removal, often adhering to refractory walls. Occasionally, unconsumed or charred bits of cloth or paper are found, but when compared against the original input it turns out they are a poor guide to the efficiency of the overall combusion process. (See Photograph 10).

Table 6 shows the volumes, weights, and bulk densities of the residues from the burn down of each day's input waste at each test site.

TABLE 6

RESIDUE ANALYSIS

Plant And Test Day	Residue Volume (Cu. Ft.)	Net Weight of Residue (Lbs.)	Bulk Density (Lbs./Cu. Ft.)
Orlando			
1	128	6980	54.53
2	117	7320	62.56
3	127	6120	48.19
4	208	9160	44.04
Average	145	7395	52.33
Pahokee			
1	83	2670	32.17
2	85	4235	49.82
3	88	3020	34.32
4	136	4440	32.65
Average	98	3591	37.24
Siloam Springs			
1	104	5120	49.23
2	123	5580	45.37
3	71	3240	45.63
Average	99	4647	46.74



The residue removal system shown in these photographs was used in all the plants that were surveyed.

Ash residue is removed each morning after cooling and before the incinerators are started.

The entire end dome of the incinerator opens to permit complete access to the primary chamber.

Removal is done by the use of a rake attached to the front of the plant tractor. Residue is piled onto the concrete pad and then loaded into a dump truck for hauling to the adjacent land fill. Volume reductions are over 90%.

Photograph 10
TYPICAL RESIDUE FROM
THE TEST INCINERATORS

CHAPTER 10

STACK EMISSION TESTING

The Test Plan

Before the test week began at each site, the manufaturer and the plant crew checked all machines to ensure they were in proper operating condition. Arrangements were completed to ensure they would be operated under normal conditions during testing. Scaffolding and platforms were erected to provide access to the sampling ports and to hold the test equipment.

The test incinerators were chosen at random at each site — one from the eight at Orlando and one from each of the two installed at both Pahokee and Siloam Springs.

All source test runs at each plant were conducted in a similar manner, so the results are comparable. It is required to make four sampling runs for determining the air emission characteristics of an incinerator under EPA procedures. This method was followed. However, if in a later detailed examination of the data on each test, it is determine that ± 10% of isokinetic conditions were not met at any time, the results of the particular run involved should be discarded and not published. Isokinetic sampling conditions exist when the velocity of the gases entering the sampling nozzle tip equal the velocity of the stack gases at the traverse points being sampled.

At Orlando, isokinetic conditions were met in all four test runs and hence data on all four appear in this report. At both Pahokee and Siloam Springs, one run was discarded due to this effect and the results of only three runs are published at both sites.

Stack Emission Test Protocol

The elapsed air testing time averaged from two and one half to over four hours for each test. Before each test the machine was emptied of residue, warmed to running temperature, and charged for at least one-half hour, to ensure it had reached steady-state conditions.

Testing of continuously operated incinerators presents different conditions than with batch type units. With the latter, the EPA procedure permits reaching stable conditions and maintaining these during testing. The present study followed this protocol. To our knowledge, tests of the emissions during the warm-up and burn-down periods have not been published by researchers. It is felt that future studies should investigate the environmental effects during such "unstable" periods of operation for batch type incinerators.

Source testing of each incinerator was conducted through sample ports in the exhaust stack downstream from a fresh air inductor. The components of the particulate sampling train used were a probe, filter, four impingers, dry gas meter, vacuum pump, and flow meter (see Figure 16).

The probe is continually repositioned within the stack at a series of sampling (traverse) points during air testing, and held in each position for at least three minutes to ensure that the entire cross section of the stack is adquately covered during a test. The probe is connected to a glass fiber filter contained in an electrically heated enclosed box. The atmosphere in the box is thermostatically maintained at a temperature high enough to prevent water condensation occuring in this portion of the sample train. The gas, captured by the probe, passes through the filter and then through four impingers that are installed in an ice bath. The first two contain distilled water, the third is left dry, and the fourth contains silica gel. The sampled gas then flows through a leakless vacuum pump and a dry gas meter to a calibrated orifice that measures instantaneous flow rates.

A calibrated pitot tube for measuring gas velocity pressure in the stack and a thermocouple for measuring stack gas temperatures, are attached to the sample collection probe. This permits simultaneous measurement of point velocity pressures and gas temperatures at each sampling point. One leg of the pitot tube is connected to a manometer for measuring gas pressure. From these readings average velocity is calculated; as are average, maximum and minimum temperatures, and the absolute temperature ratio. By recording the manometer differential the absolute gas pressure is calculated.

It is important to select the proper size of sampling nozzle for testing not only gas velocity, but also pressure and temperature at the sampling locations, and to assist in obtaining isokinetic conditions. Nozzle diameters are chosen that produce a meter flow rate in the range of 0.6 to 1 cu. ft. per minute. At the three test sites, a 1/2" I.D. nozzle was used throughout.

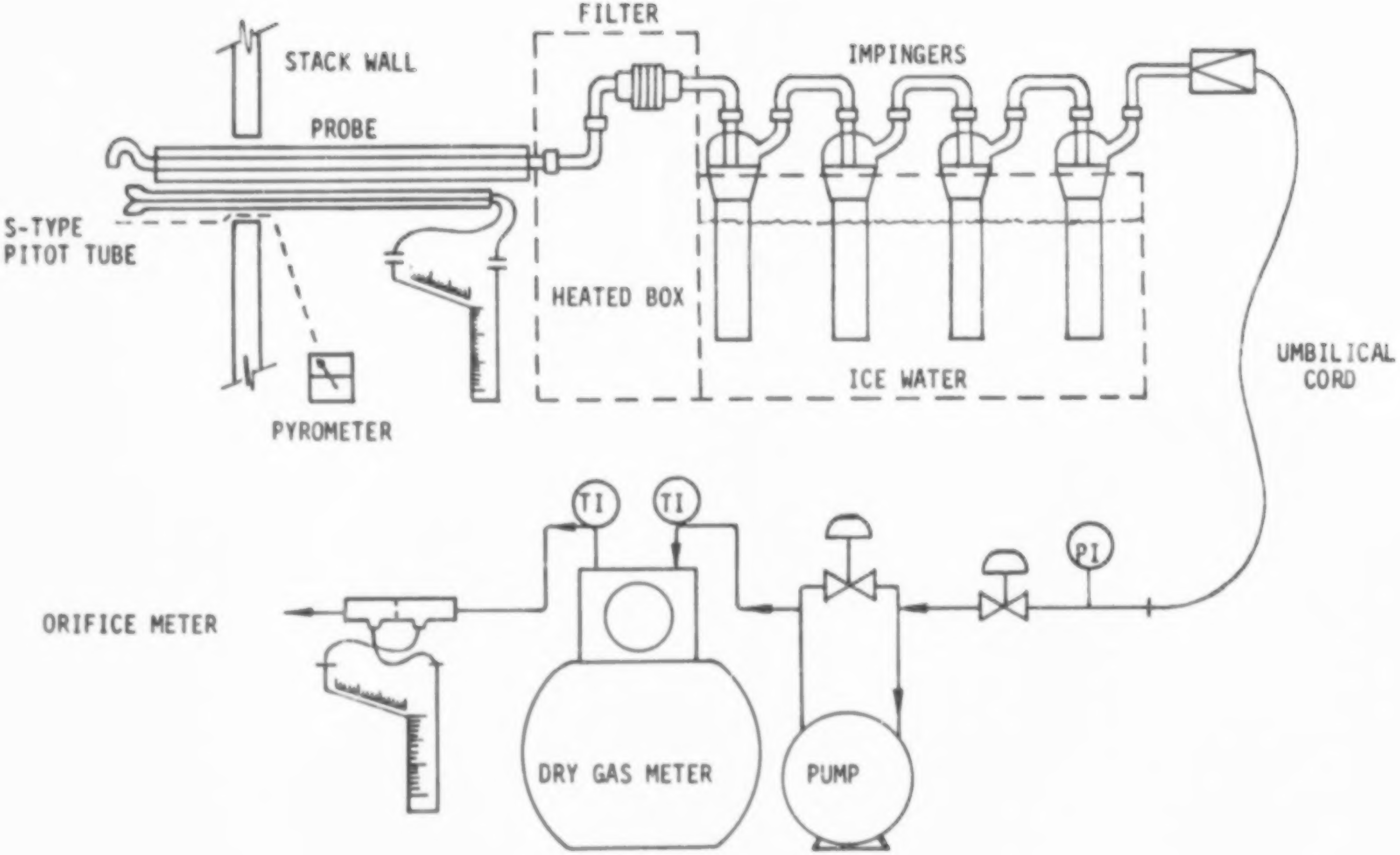

FILTER
STACK WALL
IMPINGERS
PROBE
S-TYPE
PITOT TUBE
HEATED BOX
ICE WATER
UMBILICAL
CORD
PYROMETER
TI
TI
PI
ORIFICE METER
DRY GAS METER
PUMP

Figure 16 . SCHEMATIC DRAWING OF SAMPLE TRAIN

Sampling Traverse Points

The numbers and locations of the sampling points within the stack are as important as length of sampling at each point, in order to ensure an accurate test. These sampling points are chosen on a formula that considers the location of the sampling ports in relation to bends and obstructions in the stack, the configuration and size of the stack cross section and on the degree of variations in stack flow conditions existing at the sampling locations. Every effort is made to obtain a representative series of measurements that permit calculating average values.

The sample port locations chosen at the test sites were in the vertical stack and located approximately two stack diameters downstream from any bend, size change or visible flame in the stack and approximately one stack diameter upstream from any bend or obstruction.

The incinerators all employed circular stacks. The practice in testing is to divide the cross sectional area of a circular configuration into a number of concentric, equal-area zones. Traverse points should be located at the centroid of each equal area ± 1/4 inch in any direction. Based on the diameters of the stacks involved, it was determined that a total of 48 traverse points would be required for valid sampling.

The stack is divided into a number of concentric equal area zones. Traverse points are located in centroid of each zone.
48 points were required to adequately traverse each stack.

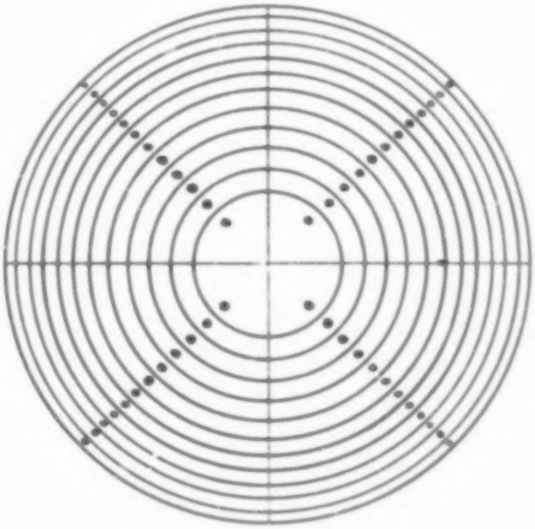


Figure 17. SAMPLING POINTS FOR STACK TRAVERSES

Gas Sample Collection

Integrated gas samples were collected from the sampling train during each test at each incinerator to determine the make up of these gases. Figure 18 is a schematic rendition of the system and devices used to collect this sample. Analysis of the gas collected is made by the use of an Orsat analyzer. Molecular weight of the stack gases is calculated from the moisture determination data and the dry gas composition data.

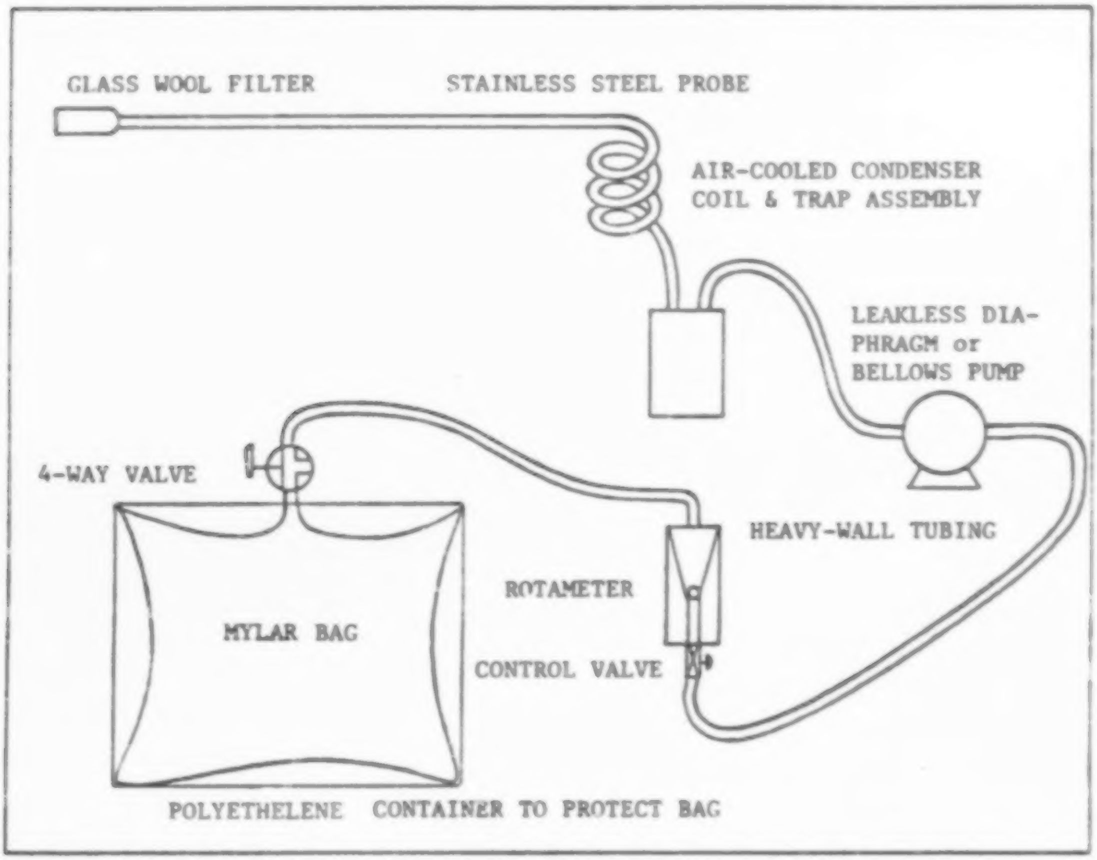
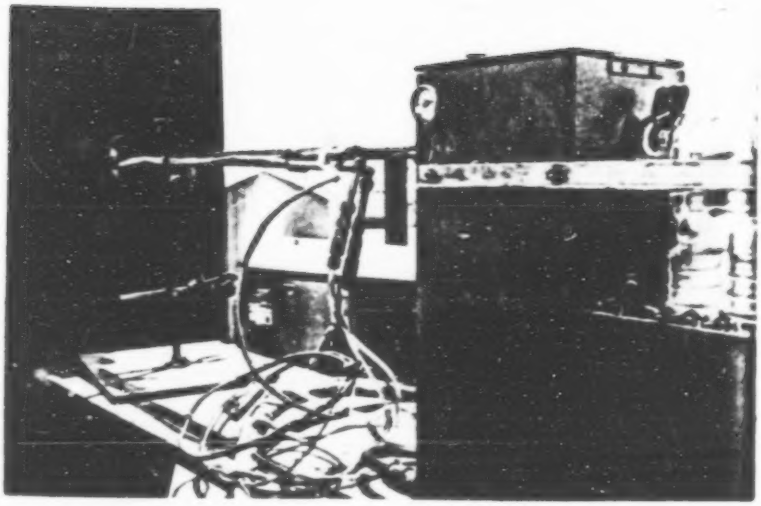
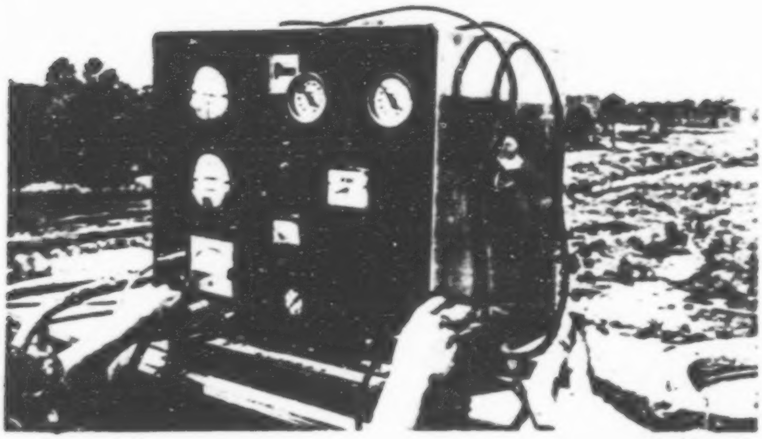

GLASS WOOL FILTER
STAINLESS STEEL PROBE
AIR-COOLED CONDENSER COIL & TRAP ASSEMBLY
LEAKLESS DIAPHRAGM or BELLOWS PUMP
4-WAY VALVE
HEAVY-WALL TUBING
ROTAMETER
MYLAR BAG
CONTROL VALVE
POLYETHELENE CONTAINER TO PROTECT BAG

Figure 18. DRY GAS COMPOSITION SAMPLE EQUIPMENT

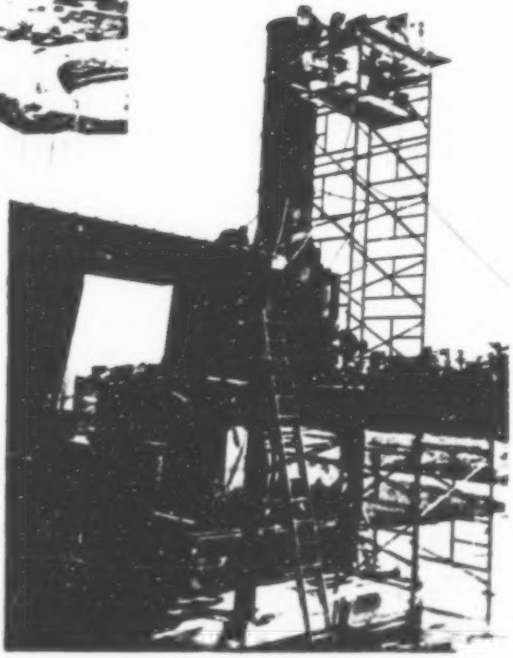
The Photographs on pages 79 and 80 show the arrangement of equipment for air testing at each plant.



The photograph shows the probe inserted in a sample port in the stack. The probe connects to the impinger box, entering a heated chamber. The gas is then passed through four impingers inserted in an ice bath.



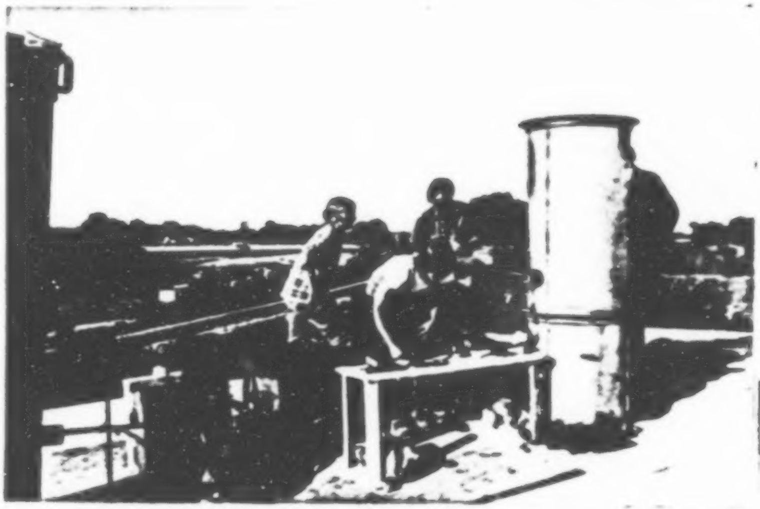
The meter box shown is the control console for stack testing and contains instruments for monitoring gas temperature and pressure, a vacuum pump, valving to control the flow of gas, and a totalizing gas meter.



Typical scaffolding arrangement with a platform installed at the top for stack testing.

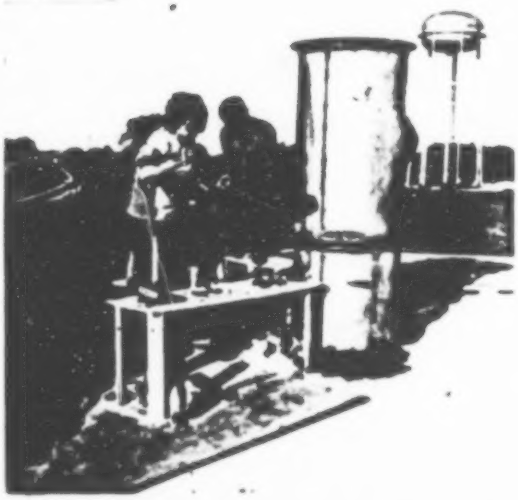
Photograph 11
STACK EMISSION TESTING INSTRUMENTS

Siloam Springs offered a unique challenge in the stack testing. This was the first time a small incinerator modular plant, producing steam, has been tested for emissions under normal operating conditions.



Testing two stacks simultaneously presents logistical problems not found in single stack studies. The center photograph shows a probe in the sample port of each stack.

The smaller, light colored stack carried the effluent gas from the boiler. The larger stack is the dump stack that is connected directly to the incinerator.



Photograph 12
DUAL STACK
EMISSION TESTING INSTRUMENTATION

Visible Emissions

Visible emissions were infrequent. Occasional pieces of flyash were emitted and these could usually be associated with the explosion of an aerosol or paint can in the lower chamber.

Previous experience has shown that short periods of visible emissions from controlled air incinerators can be accounted for by disturbances in combustion air feed. These, in turn, can be caused by air controls, loader jams, explosions of the waste, and lag time in sensing and controlling systems. One case of smoke with an opacity greater than Ringleman No. 1 was noted during testing at Pahokee and this was near the beginning of the first test run for a duration of about three minutes. No visible emissions exceeding Ringleman No. 1 were noted from the units tested at Orlando and Siloam Springs. Brief periods of opacity of 5 percent and 10 percent were noted periodically, lasting as long as 30 seconds. These could sometimes be correlated to the injection of water into the lower chamber for temperature control. This was especially true during Run No. 3 at the Orlando site. At other times at both Orlando and Siloam Springs, these occurred after explosions in the waste, in all probability caused by aerosol cans.

This points out another problem in categorizing visible emissions from these units. Burning rate in the lower chamber is controlled with water sprays. When these sprays are activated, some steam is emitted from the unit. Since most of the logged visible emissions from the units tested are in the 5 to 10 percent opacity range and not black in color, it is difficult to say whether water vapor was the main contributor to plume opacity.

Interpretation of Stack Testing Results

Reported for each site is a summary table of particulate emission testing results. This is followed by a table showing the results in various standard methods, along with detailed parameters of the stack exhaust conditions. The fourth table for each site summarizes the analysis of the exhaust gases.

Auxiliary Fuel

Pahokee burns #2 fuel oil for auxiliary fuel. Orlando and Siloam Springs utilize natural gas. Both fuels contribute CO_2 to the exhaust gases.

Separate fuel flow totalizing meters were installed on each chamber in each of the test incinerators. Readings were taken continually during each test run.

At Pahokee the meter on the secondary chamber malfunctioned during testing; however, total fuel consumptinn was recorded. At each site the average fuel consumed per minute during testing was calculated. From this the amount of CO_2 generated per minute and the contribution of CO_2 due solely to the auxiliary fuel was calculated.

Each pound of #2 oil that is burned produces an average of 27.8 $ft.^3$ of CO^2. At 7.4 pounds weight for a gallon of #2 oil, this would be 205.7 $ft.^3$ of CO^2 per gallon of oil burned. Natural gas is a "cleaner" fuel and releases less CO_2 proportionately. For each cubic foot of gas burned, an average 1.0628 $ft.^3$ of CO_2 is released. A comparison between the two fuels shows that 140 $ft.^3$ of natural gas produces 140,000 Btu and releases 148.8$ft.^3$ of CO_2 while a gallon of #2 oil produces 140,000 Btu. and releases 205.7 $ft.^3$ of CO_2.

Emission Test Results, Pahokee, Florida

Testing commenced on May 12, 1975 and continued through May 15. Incinerator Unit #1 was chosen at random. Waste for all tests was relatively wet (see Table 19), mostly residential garbage. Charge rates were monitored and are reported in Chapter 7. Burn rates per hour were based on total burn rates per day. Chapter 8 reports the waste composition.

The average particulate (Dry Catch) emission of the three test runs was 0.0654 grains per standard cubic foot of dry stack exhaust corrected to 12 percent CO_2 with the contribution of CO_2 by auxiliary fuel subtracted. The average of the total catch (dry plus wet) was 0.0760, and under 0.08 gr/SCFD, which is the Federal New Source Performance Standard for "large" incinerators (50 tons per day or greater). The mass emission rate was .8898 pounds/hour in the dry catch. The data for each run is given in Tables 7, 8, 9 and 10. Appendix C contains additional detail.

TABLE 7

SUMMARY OF PARTICULATE TEST RESULTS

PAHOKEE, FLORIDA

		Emission Concentration				Stack Exhaust Conditions		
		Dry Catch	Wet Catch	Total Catch	Mass Emission Rate Dry Catch (lbs/hr)	Volumetric ACFM≠	Exhaust Flow SCFMD‡	Stack Temp. (°F)
Date	Test #	GN/SCFD* @ 12% CO_2						
5/13/75	1	.0553	.0101	.0654	.8868	10625	3411	1002
5/14/75	2	.0793	.0151	.0944	.9745	9019	3008	919
5/15/75	3	.0616	.0067	.0683	.8080	8443	2690	981
AVERAGE (3 runs included)		.0654	.0106	.0760	.8898	9362	3036	967

* Grains/Standard Cubic Feet, Dry
≠ Actual Cubic Feet Min.
‡ Standard Cubic Feet Min., Dry

TABLE 8

SUMMARY OF PARTICULATE EMISSION TEST RESULTS

PARTICULATE EMISSIONS TEST PAHOKEE, FLORIDA INCINERATOR

	Test Run No. & Date			
	1 5/13/75	2 5/14/75	3 5/15/75	Avg. of 3 Test Runs
Charge Rate (Lbs/Hr)	1759	1844	1669	1757
Burn Rate (Lbs/Hr)	1304	1180	1179	1221
Testing Periods: Start-up Time	8:15	9:00	8:07	
First Charge	8:43	9:15	8:53	
Start Test	9:49	10:20	9:48	
TOTAL TEST TIME	4 hr. 30 min.	4 hr. 20 min.	4 hr. 23 min.	
DRY CATCH				
Lbs/Hr	.8868	.9745	.8080	.8898
GN/ACF*	.0097	.0126	.0112	.0112
GN/SCFD†	.0267	.0331	.0303	.0300
GN/SCFD 12 CO_2	.0553	.0793	.0616	.0654
GN/SCFD 3.5 CO_2	.0161	.0231	.0180	.0191
GN/SCFD 50 Excess Air	.0442	.0548	.0444	.0478
Lbs/100 Lbs Charged	.0502	.0527	.0481	.0503
Lbs/100 Lbs Burned	.0732	.0931	.0764	.0809
Lbs/1000 Lbs Flue Gas	.0488	.0602	.0556	.0549
CONDENSER CATCH				
Lbs/Hr	.1619	.1860	.0872	.1450
GN/ACF	.0018	.0024	.0012	.0018
GN/SCFD	.0049	.0063	.0033	.0048
GN/SCFD 12 CO_2	.0101	.0151	.0067	.0106
TOTAL				
Lbs/Hr	1.0487	1.1605	.8952	1.0348
GN/ACF	.0115	.0150	.0124	.0130
GN/SCFD	.0316	.0394	.0336	.0349
GN/SCFD 12 CO_2	.0654	.0944	.0683	.0760

* Grains/Actual Cubic Feet

† Grains/Standard Cubic Feet, Dry

TABLE 9

EXHAUST GAS CONDITIONS IN STACK

PAHOKEE, FLORIDA INCINERATOR

	Test Run No. & Date			
	1 5/13/75	2 5/14/75	3 5/15/75	Avg. of 3 Test Runs
Velocity, Ft/Min	1314.94	1116.19	1044.96	1158.70
Temperature, Deg F	1002	919	981	967
Volume, Actual Cubic Feet / Min.	10625	9019	8443	9362
Volume, Standard Cubic Feet / Min. Dry	3411	3003	2690	3037
Moisture, By Volume Condensate Method	11.63	13.36	13.44	12.81
Auxiliary Fuel Consumed (lbs/min)	1.085	1.19	1.2	1.16
Average Velocity of Sampled Gases at Nozzle Ft/Min.	1265.58	1085.76	1081.8	1144.38
% Isokinetic	96.2	97.3	103.5	99.0

TABLE 10

SUMMARY OF EXHAUST GAS ANALYSIS

PAHOKEE, FLORIDA INCINERATOR

	Test Run No. & Date			
	1 5/13/75	2 5/14/75	3 5/15/75	Avg. of 3 Test Runs
CO_2 (Total)	6.70	6.00	6.90	6.53
CO_2 in Fuel	.9	1.1	1.1	1.03
Net CO_2 in Stack Gas	5.80	5.01	5.90	5.57
CO ppm	.20	.73	.30	.41
O_2%	12.70	12.80	11.70	12.40
N_2%	80.60	81.20	81.40	81.07
Dry Molecular Weight	29.58	29.47	29.57	29.54
Mol. Wt. w/Moisture	28.23	27.94	28.02	28.06

Emission Test Results, Orlando, Florida

During the week of May 19, 1975, the survey team conducted four complete particulate emission test runs at the Orlando Incinerator Plant. Incinerator Unit #5 was chosen at random from the eight units at this site.

Waste charging and composition rates were monitored as reported in Chapters 7 and 8. Waste composition varied greatly throughout the week of testing. As the week progressed, a higher percentage of commercial waste was delivered. Several paint cans were noted. Explosions of aerosol cans in the lower chamber disrupted the process for several seconds to several minutes. When these conditions occur, mass emission rate increases and usually a plugged filter in the sample train ensues. Average CO_2 concentrations in the exhaust increased during the later runs, indicating a higher burn rate. On May 22, this this burn rate appeared to exceed the controlled burning capability of the second chamber.

The May 22 test run exceeded the New Source Performance Standard. As a result, the average of the runs slightly exceeded 0.08 grains per standard cubic foot of dry exhaust corrected to 12% CO_2.

The data for each test is given in Tables 11, 12, 13 and 14. Additional details are in Appendix C.

TABLE 11

SUMMARY OF PARTICULATE TEST RESULTS

ORLANDO, FLORIDA

Date	Test #	Emission Concentration			Mass Emission Rate	Stack Exhaust Conditions		
		Dry Catch	Wet Catch	Total Catch	Dry Catch (lbs/hr)	Volumetric ACFM †	Exhaust Flow SCFMD ‡	Stack Temp. (^0F)
		GN/SCFD* @ 12% CO_2						
5/19/75	1	.0629	.0032	.0662	1.24	11600	4161	847
5/20/75	2	.0800	.0049	.0849	1.57	12726	4074	994
5/21/75	3	.0754	.0027	.0777	1.83	13396	4126	1019
5/22/75	4	.1190	.0061	.1251	2.62	13986	4110	1077
AVERAGE (4 runs included)		.0843	.0042	.0885	1.82	12927	4118	984

* Grains/Standard Cubic Feet, Dry

† Actual Cubic Feet / Min.

‡ Standard Cubic Feet / Min., Dry

TABLE 12

SUMMARY OF PARTICULATE EMISSION TEST RESULTS

PARTICULATE EMISSIONS TEST ORLANDO, FLORIDA INCINERATOR

	Test Run No. & Date				
	1 5/19/75	2 5/20/75	3 5/21/75	4 5/22/75	Avg. of 4 Test Runs
Charge Rate (Lbs/Hr)	2951	2860	2586	3157	2889
Burn Rate (Lbs/Hr)	2168	2177	1933	2290	2142
Testing Periods:					
Start-up Time	8:00	8:00	7:15	7:00	
First Charge	8:39	9:15	7:48	8:05	
Start Test	9:42	10:15	8:45	8:30	
TOTAL TEST TIME	4 hr. 39 min.	4 hr 0 min.	4 hr 35 min.	4 hr. 0 min.	
DRY CATCH					
Lbs/Hr	1.2407	1.5700	1.8295	2.6236	1.8160
GN/ACF*	.0125	.0144	.0159	.0219	.0162
GN/SCFD†	.0308	.0392	.0470	.0669	.0460
GN/SCFD 12 CO_2	.0629	.0800	.0754	.1190	.0843
GN/SCFD 3.5 CO_2	.0183	.0233	.0220	.0347	.0770
GN/SCFD 50 Excess Air	.0465	.0599	.0717	.1072	.0713
Lbs/100 Lbs Charged	.0417	.0545	.0710	.0943	.0654
Lbs/100 Lbs Burned	.0633	.0774	.1016	.1309	.0933
Lbs/1000 Lbs Flue Gas	.0559	.0720	.0812	.1167	.0815
CONDENSER CATCH					
Lbs/Hr	.0634	.0962	.0675	.1349	.0905
GN/ACF	.0006	.0009	.0006	.0011	.0008
GN/SCFD	.0016	.0024	.0017	.0034	.0023
GN/SCFD 12 CO_2	.0032	.0049	.0027	.0061	.0042
TOTAL					
Lbs/Hr	1.3041	1.6662	1.9174	2.7585	1.9116
GN/ACF	.0131	.0153	.0169	.0230	.0171
GN/SCFD	.0323	.0416	.0488	.0703	.0483
GN/SCFD 12 CO_2	.0661	.0849	.0781	.1252	.0885

* Grains/Actual Cubic Feet

† Grains/Standard Cubic Feet, Dry

TABLE 13

EXHAUST GAS CONDITIONS IN STACK

ORLANDO, FLORIDA INCINERATOR

	Test Run No. & Date				
	1 5/19/75	2 5/20/75	3 5/21/75	4 5/22/75	Avg. of 4 Test Runs
Velocity, Ft/Min	1363.05	1495.47	1574.13	1643.48	1519.03
Temperature, Deg F	847	994	1019	1077	984.25
Volume, Actual Cubic Feet, Min.	11600	12726	13396	13986	12927
Volume, Standard Cubic Feet, Min. Dry	4161	4074	4126	4110	4117.75
Moisture, By Volume Condensate Method	11.70	12.40	14.34	15.08	13.38
Auxiliary Fuel Consumed (ft^3/min)	33.3	28.8	20.5	18.6	25.30
Average Velocity of Sampled Gases at Nozzle Ft/Min.	1334.4	1391.4	1608.0	1637.4	1492.8
% Isokinetic	97.9	93.1	102.1	99.6	98.2

TABLE 14

SUMMARY OF EXHAUST GAS ANALYSIS

ORLANDO, FLORIDA INCINERATOR

	Test Run No. & Date				
	1 5/19/75	2 5/20/75	3 5/21/75	4 5/22/75	Avg. of 4 Test Runs
CO_2 (Total)	6.70	6.60	8.00	7.20	7.13
CO_2 in Fuel	.83	.75	.52	.48	.645
Net CO_2 in Stack Gas	5.87	5.88	7.49	6.74	6.50
CO ppm	(not measured)	<10.	0.	<10.	0.
O_2%	12.00	12.10	11.90	12.40	12.1
N_2%	81.30	81.30	80.10	80.40	80.78
Dry Molecular Weight	29.55	29.54	29.76	29.65	29.63
Mol. Wt. w/Moisture	28.20	28.11	28.07	27.89	28.07

Emission Test Results, Siloam Springs, Arkansas

During the period of October 1 through 4, 1975, the survey team conducted three test runs on one of the incinerators and its matching steam boiler that was installed in the Siloam Springs plant. Two tests were run on the boiler stack and one on the heat dumping, or normal incinerator, exhaust.

The first two regular tests were conducted entirely on the gas emitted by the boiler exhaust stack. Full steam production was called for during these two runs and consequently 100 percent of the exhaust flow passed through the boiler and out the boiler stack. Constant monitoring of the heat dumping stack confirmed that all exhaust passed through the boiler.

The results of the two tests averaged 0.0301 grains per standard cubic foot of dry exhaust gases corrected to 12% CO_2. Auxiliary fuel consumption during each test was low enough that no correction for CO_2 produced by the fuel was required.

The third test was conducted with steam production not in operation. All gases from the incinerator were exhausted directly to the atmosphere, bypassing the boiler entirely. The result of this test averaged 0.0367 grains per standard cubic foot of dry exhaust corrected to 12% CO_2. In this case also, the fuel consumption was so low that no correction for CO_2 produced by the fuel was required.

Waste charging and composition rates were monitored and are reported in Chapters 7 and 8. Visible emissions were noted infrequently and were usually associated with an audible explosion (possibly aerosol cans) within the unit. The exhaust temperature from the boiler stack was extremely low when compared to the exhaust of the main, or dumping, stack. This would indicate excellent heat absorption, and hence efficiency rate, in the boiler itself.

The data for each test is given in Tables 15, 16, 17 and 18.

TABLE 15

SUMMARY OF PARTICULATE TEST RESULTS

SILOAM SPRINGS, ARKANSAS

Date	Test #		Emission Concentration			Mass Emission Rate	Stack Exhaust Conditions		
			Dry Catch	Wet Catch	Total Catch	Dry Catch (lbs/hr)	Volumetric ACFM †	Exhaust Flow SCFMD ‡	Stack Temp. (°F)
			GN/SCFD* @ 12% CO_2						
10/3/75	1	(A)	.0267	.0402	.0668	.2923	7192	4754	273
10/3/75	2	(A)	.0336	.0303	.0640	.5613	9553	6616	254
Avg. of 2 runs			.0302	.0353	.0654	.4268	8373	5685	264
10/4/75	3	(B)	.0367	.0102	.0463	.4456	9046	2519	1333

(A) During these two tests all gas was being emitted from the boiler stack, as full steam production was in effect. The aero-dynamic valving prevented any gas from escaping through the main or dump stack. Note the low heat of the gas as it entered the boiler stack, indicating an extremely high rate of efficiency in heat extraction by the boiler tubes.

(B) During the third test the boiler was shut down and all gases diverted to the main stack. Note the extreme rise in gas temperature.

* Grains/Standard Cubic Feet, Dry. † Actual Cubic Feet / Min. ‡ Standard Cubic Feet / Min., Dry

TABLE 16

SUMMARY OF PARTICULATE EMISSION TEST RESULTS

PARTICULATE EMISSIONS TEST SILOAM SPRINGS, ARKANSAS, INCINERATOR

	Test Run No. & Date			
	1 10/3/75	2 10/3/75	Avg. of 2 Test Runs	3 10/4/75
Charge Rate (Lbs/Hr)	2478	2392	2435	2680
Burn Rate (Lbs/Hr)	1635	1673	1654	1527
Testing Periods:				
Start-up Time	9:00	9:00		8:00
First Charge	10:00	10:00		9:00
Start Test	11:34	2:47		10:02
TOTAL TEST TIME	2 hr. 32 min.	2 hr. 30 min.		2 hr. 32 min.
DRY CATCH				
Lbs/Hr	.2923	.5613	.4268	.4456
GN/ACF*	.0047	.0069	.0058	.0057
GN/SCFD†	.0069	.0090	.0080	.0202
GN/SCFD 12 CO_2	.0267	.0336	.0302	.0367
GN/SCFD 3.5 CO_2	.0078	.0098	.0088	.0107
GN/SCFD 50 Excess Air	.0165	.0250	.0208	.0374
Lbs/100 Lbs Charged	.0122	.0236	.0179	.0165
Lbs/100 Lbs Burned	.0182	.0351	.0267	.0314
Lbs/1000 Lbs Flue Gas	.0119	.0166	.0143	.0343
CONDENSER CATCH				
Lbs/Hr	.4403	.5069	.4736	.1235
GN/ACF	.0071	.0062	.0067	.0016
GN/SCFD	.0104	.0081	.0093	.0056
GN/SCFD 12 CO_2	.0402	.0303	.0353	.0102
TOTAL				
Lbs/Hr	.7326	1.0682	.9004	.5691
GN/ACF	.0119	.0130	.0125	.0073
GN/SCFD	.0173	.0171	.0172	.0258
GN/SCFD 12 CO_2	.0668	.0640	.0654	.0463

* Grains/Actual Cubic Feet

† Grains/Standard Cubic Feet, Dry

TABLE 17

EXHAUST GAS CONDITIONS IN STACK

SILOAM SPRINGS, ARKANSAS, INCINERATOR

	Test Run No. & Date			
	1 10/3/75	2 10/3/75	3 10/4/75	
Velocity, Ft/Min	1950.65	2591.11	2550.44	Two separate stacks tested. Averaging not applicable.
Temperature, Deg F	273	254	1333	
Volume, Actual Cubic Feet, Min	7192	9553	9046	
Volume, Standard Cubic Feet, Min. Dry	4754	6616	2519	
Moisture, By Volume Condensate Method	7.78	5.92	4.53	
Auxiliary Fuel Consumed (ft^3/min)	1.066	0.0	0.132	
Average Velocity of Sampled Gases at Nozzle Ft/Min	1962.6	2400.	2565	
% Isokinetic	100.6	92.6	102.	

TABLE 18

SUMMARY OF EXHAUST GAS ANALYSIS

SILOAM SPRINGS, ARKANSAS INCINERATOR

	Test Run No. & Date			
	1 10/3/75	2 10/3/75	3 10/4/75	
CO_2 (Total)	3.10	3.20	6.60	Two separate stacks tested. Averaging not applicable.
CO_2 in Fuel	.02	.0	.006	
Net CO_2 in Stack Gas	3.08	3.20	6.594	
CO ppm	10.	10.	25.	
O_2%	15.5	16.20	13.50	
N_2%	81.40	80.60	79.90	
Dry Molecular Weight	29.12	29.16	29.60	
Mol. Wt. w/Moisture	28.25	28.50	29.07	

CHAPTER 11

LABORATORY ANALYSES OF RAW WASTES AND RESIDUES

Preparation of Laboratory Samples

Laboratory analysis of the waste "as received" and of the residue remaining is used in evaluating the problems that may arise in incinerating a particular waste stream, as well as evaluating a particular incinerator in dealing with such waste. The make-up of the waste affects the quality of the stack emissions, the quantity of auxiliary fuel that must be used, its worth as a fuel for energy recovery, and the weights and volumes of residue generated. The combustibles remaining in the residue indicate completeness of combustion and reduction.

The laboratory testing should determine the proximate analysis: the moisture content, the combustible and non-combustible content and the heat content of the waste and residue. It should also determine the ultimate analysis (in terms of carbon, hydrogen, sulfur, chlorine, oxygen and nitrogen). This requires laboratory samples that have been reconstituted accurately from the bulk samples that were assembled to determine waste composition.

Incinerator and waste stream testers have been performing such laboratory analyses for years, as an aid in designing incinerators, and for evaluating the results of the combustion process. With the advent of waste-heat recovery and steam production through incineration of solid wastes, there is an even more pressing need for such analysis, and on an extremely accurate basis. If the waste is to become a fuel (and a replacement for other energy sources, such as fossil fuels) we must know a great deal about it if we are to evaluate its ability to produce energy on an efficient basis.

When we examine residential, commercial and certain industrial waste, we find that we are dealing with an extremely variable product. Despite the analytical problems involved, it is essential that we develop reliable methods for determining heat output of the particular waste being burned; in order to calculate the amount of energy that can be captured in heat transfer methods of varying designs and efficiencies.

At first glance, we can see that waste is a relatively inefficient fuel compared to fossil fuels. It takes far greater weights and volumes of waste to produce the heat output found in a pound of coal, a gallon of oil, or a cubic foot of gas. Unfortunately, the problem is more complicated than this. Compared to the uniformity of weight to volume, and heat output to a unit of weight or volume, found in fossil fuels, solid waste is a product that continually varies. No two cubic yard lots of it are alike on an "as received" basis. The density (weight per cubic foot) will vary from load to load; as will the moisture content; the percentage of combustible material versus the non-combustibles; and the heat content, or Btu value, for a given unit of weight or volume.

With these conditions, the laboratory testing methods that have been used to date to determine proximate analysis and ultimate analysis of solid waste could probably be improved upon. They were originally adapted from methods used for testing more uniform products than waste. When huge flows of several tons per day of waste are reduced to a few pounds for testing purposes, the chance for error is substantial when dealing with such a variable product. The best we can hope for from the laboratory are good averages of the conditions found in the waste stream over the test period.

The same procedure was followed at each of the three plants for preparing laboratory samples of the "as received" waste. Four of the bulk samples that had been assembled at each plant to determine the composition of the waste on a percentage-by-weight basis, were selected for analysis. A 20 pound laboratory sample was then prepared daily from each, reconstituted in the exact percentages by weight found in the large sample.

Each component in the laboratory sample was kept separate in sealed plastic bags. Sealing is important to ensure that complete moisture content is retained. The combustibles were kept separate from the non-combustibles. All components were clearly identified by tags, with the exact net weights of each. Each entire 20 pound sample was double-bagged and sealed, and identified as to date and source.

Representative one cubic foot laboratory samples of the residue were also taken daily from each test incinerator. These were used to determine the proximate analysis: moisture content, ash and volatile content, and heat content, as well as to perform an ultimate analysis of the unburned combustibles and fines. These samples were also sealed in plastic bags to prevent loss of moisture, then tagged and identified as to date and source.

Proximate Analysis

The moisture content of the incoming solid waste and residue samples from each plant were determined by reconstituting the daily samples into one total sample for each plant. Moisture of the total sample is assumed to be in the combustible portion only. In each laboratory analysis the non-combustible portion of the waste sample and of the residue sample was discarded after the total moisture content had been determined. These materials (glass, metal, rock, etc.) are assumed to be inert, and will not release any practical energy upon heating.

The reconstituted combustible samples were prepared for further analysis in a manner which insured they were sufficiently homogeneous in composition to allow replicate one gram subsamples to be extracted that were representative of the entire sample.

The heat content (Btu/lb) of the combustible portion on a dry basis was then calculated, and for both waste and residue samples. From this was calculated the heat content of the "as received" waste, which, due to moisture and non-combustible portions, is always lower than the heat content of the combustible proportion on a per pound basis.

Ultimate Analysis

Ultimate chemical analyses were performed on the composite subsample of the raw waste and on the unburned combustibles in the residue to determine the percentages (by weight) of carbon, hydrogen, sulfur, chlorine, oxygen and nitrogen.

The ash contents of the prepared subsamples used for the ultimate analysis were determined. The percentages by weight as determined on a dry basis were adjusted to an "as received" basis by assuming that the samples contained only the six listed chemical elements, plus moisture and inerts. The percentages of the eight constituents were adjusted on a weight basis to 100 percent.

Tables 19 and 20 show the results of these laboratory investigations on both the wastes and the residues at all three sites. Appendix D lists the procedures and methods used.

TABLE 19

SUMMARY OF WASTE ANALYSES

ANALYSES		PAHOKEE	ORLANDO	SILOAM SPRINGS
COMPOSITION OF TOTAL SAMPLE "AS RECEIVED":				
Moisture	%	49.9	33.96	20.8
Total Dry Matter	%	50.1	66.04	79.2
Total Sample		100.0	100.00	100.0
Moisture	%	49.90	33.96	20.80
Non-Combustible	%	13.59	10.72	29.28
Combustible	%	36.51	55.32	49.92
Total Sample		100.00	100.00	100.00
COMPOSITION OF DRY PORTION:				
Non-Combustible	%	27.13	16.23	36.97
Combustible	%	72.87	83.77	63.03
Total		100.00	100.00	100.00
ANALYSIS OF COMBUSTIBLE PORTION:				
Carbon	%	39.42	39.90	47.3
Chloride (Total)	%	.12	.12	0.759
Hydrogen	%	5.92	6.02	7.12
Nitrogen	%	1.14	1.48	0.528
Oxygen	%	39.72	41.68	35.54
Sulfur	%	.09	.08	0.10
Ash	%	13.59	10.72	5.51
HEAT CONTENT (Btu/Lb)				
In Dried Combustible Portion		6596	6973	8720
In Total "As Received" Waste		2408	3857	4353

TABLE 20

SUMMARY OF RESIDUE ANALYSES

ANALYSES		PAHOKEE	ORLANDO	SILOAM SPRINGS
COMPOSITION OF TOTAL SAMPLE "AS RECEIVED":				
Moisture	%	0.05	.05	9.24
Total Dry Matter	%	99.95	99.95	90.76
Total Sample		100.00	100.00	100.00
Moisture	%	0.05	0.05	9.24
Non-Combustible	%	94.33	94.51	55.42
Combustible	%	5.62	5.44	35.34
Total Sample		100.00	100.00	100.00
COMPOSITION OF DRY PORTION:				
Non-Combustible	%	94.38	94.56	61.06
Combustible	%	5.62	5.44	38.94
Total Sample		100.00	100.00	100.00
ANALYSIS OF COMBUSTIBLE PORTION:				
Carbon	%	2.31	2.40	18.9
Chloride (Total)	%	0.28	0.31	0.331
Hydrogen	%	0.06	0.06	1.4
Nitrogen	%	0.31	0.13	0.252
Oxygen	%	2.18	2.18	2.76
Sulphur	%	.53	.41	0.33
Ash	%	94.33	94.51	76.3
HEAT CONTENT (Btu/Lb):				
In Dried Combustible Portion		301	306	2370
In Total "As Received" Residue		16	17	838

CHAPTER 12

INCINERATOR EFFICIENCY

Various calculations determine the efficiency of performance of incinerator systems. The percent of weight reduction and the percent of volume reduction in converting the waste to an ash residue are the most obvious indicators. This involves measuring and weighing the "as received" waste and the residue remaining, and comparing the two sets of data. In addition, there is the percent of available heat released; and the combustible material remaining in the residue that can be driven off by further heating. This involves chemically analyzing the raw waste and the residue; and determining the heat that can be driven off from each. From the viewpoint of efficiency in minimizing impact on the air environment,emissions from the stack are the determining factors.

Another factor determining the efficiency of controlled air incinerators is the comparison of the auxiliary fuel consumption against the pounds of waste burned in a given period.

Chapter 11 shows the efficiency of each of the tested incinerators from the viewpoint of extraction of the heating value of the waste. In short, the analysis of the residual values in the residue compared to the original waste shows the thoroughness of the combustion process. Chapter 10 reveals the treatment of the gases and the degree of emission of potentially harmful substances into the air environment.

Tables 21, 22 and 23 show the weight and volume reductions from the "as received" waste to the residue, on each of the test days at each plant, as well as the overall average reductions for the entire test period at each. They also relate the consumption of auxiliary fuel to each ton of waste destroyed. From this aspect, the efficiencies of each incinerator were remarkably close when the averages are examined.

TABLE 21

WASTE REDUCTION - PAHOKEE

WEIGHT REDUCTION

Sample No.	Total Weight of Waste (Lbs.)	Total Weight of Residue (Lbs.)	Weight Reduction (%)
1	9,780	2,670	72
2	15,130	4,235	72
3	9,830	3,020	69
4	12,040	4,440	63
Average	11,695	3,591	69

VOLUME REDUCTION - PAHOKEE

Sample No.	Total Weight of Waste (Lbs.)	Average Density (Lbs./Ft.^{3})	Total Volume of Waste (Cu. Ft.)	Total Volume of Residue (Cu. Ft.)	Volume Reduction (%)
1	9,780	10.5	933	83	91
2	15,130	9.7	1560	85	94
3	9,830	13.0	756	88	88
4	12,040	11.4	1056	136	87
Average	11,695	11.2	1076	98	90

FUEL CONSUMPTION - PAHOKEE *

Test Day	Total Weight of Waste (lbs.)	Total 24 hr. Oil Consumed (gals.)	Oil Per Ton of Waste Burned (gals.)
1	9,780	88	18
2	15,130	127	17
3	9,830	89	18
4	12,040	111	18
Average	11,695	104	18

*Fuel Cost per ton of waste burned during testing @ 0.43 gal. #2 oil = $7.74

TABLE 22

WASTE REDUCTION - ORLANDO

WEIGHT REDUCTION

Sample No.	Total Weight of Waste (Lbs.)	Total Weight of Residue (Lbs.)	Weight Reduction (%)
1	24,500	6,980	71
2	27,360	7,320	73
3	22,940	6,120	73
4	25,040	9,160	63
Average	24,960	7,395	70

VOLUME REDUCTION - ORLANDO

Sample No.	Total Weight of Waste (Lbs.)	Average Density (Lbs./Ft.^{3})	Total Volume of Waste (Cu. Ft.)	Total Volume of Residue (Cu. Ft.)	Volume Reduction (%)
1	24,500	19.1	1283	128	90
2	27,360	11.7	2338	117	95
3	22,940	8.4	2731	127	95
4	25,040	10.8	2319	208	91
Average	24,960	12.5	2168	145	92

FUEL CONSUMPTION - ORLANDO *

Test Day	Total Weight of Waste (lbs.)	Total 24 hr. Gas Consumed (Cu. Ft.)	Gas Per Ton of Waste Burned (Cu. Ft.)
1	24,500	22,100	1804
2	27,360	15,400	1126
3	22,940	13,000	1130
4	25,040	11,200	895
Average	24,960	15,425	1239

* Fuel cost per ton of waste burned during testing @ $1.30/mcf gas = $1.62

TABLE 23

WASTE REDUCTION - SILOAM SPRINGS

WEIGHT REDUCTION

Sample No.	Total Weight of Waste (Lbs.)	Total Weight of Residue (Lbs.)	Weight Reduction (%)
1	14,420	5,120	65
2	16,696	5,580	67
3	10,640	3,240	70
Average	13,919	4,647	67

VOLUME REDUCTION - SILOAM SPRINGS

	Total Weight of Waste (Lbs.)	Average Density (Lbs./Ft.^{3})	Total Volume of Waste (Cu. Ft.)	Total Volume of Residue (Cu. Ft.)	Volume Reduction (%)
1	14,420	8.7	1657	104	94
2	16,696	6.9	2420	123	95
3	10,640	7.6	1400	71	95
Average	13,919	7.7	1826	99	95

FUEL CONSUMPTION - SILOAM SPRINGS *

Test Day	Total Weight of Waste (lbs.)	Total 24 hr. Gas Consumed (Cu. Ft.)	Gas Per Ton of Waste Burned (Cu. Ft.)
1	14,420	3590	499
2	16,696	3610	433
3	10,640	2055	388
Average	13,919	3085	440

* Fuel Cost per ton of waste burned during testing @ $0.92 mcf gas = $0.40

CHAPTER 13

ECONOMIC ANALYSIS

Capital Costs

Design and engineering costs for the modular small incinerator plants are low. Mechanization is considerably reduced compared to large scale municipal incinerator plants: overhead cranes, storage pits, residue quench tanks, expensive pollution control devices (dry or wet), and high stacks are not utilized. Hence, plant construction is considerably simplified and much less expensive per ton of installed capacity compared to the large plants.

Incinerators of over 300 tons per day, installed between 1965 and 1967, reflected capital investments ranging from $5,000 to $8,500 per ton. In 1973, a 300 ton per day plant had a capital cost of $11,000 per design ton[5]. The modular incinerator plants in the present study ranged from $9,093 per ton of design capacity at Orlando to $9,495 at Pahokee, to $17,667 with steam production capability at Siloam Springs.

A direct comparison proved difficult between the small and large municipal plants for the cost of steam production equipment. The few large plants attempting energy recovery to date have installed more complicated systems. In sheer dollars, where the modular plants show a capital investment of under $110,000 for steam recovery boilers, the large plants have spent many times this figure. In 1973 it averaged $16,000 per design ton.[6]

Table 24 shows the breakdown of capital investment at the test sites for the incinerator equipment, all structures, and their service utilities to bring the plant "on line". In Pahokee and Orlando, the land was owned by the municipality several years before the incinerator plant was located on it. The town of Siloam Springs pays Allen Canning Company $1.00 per year on a twenty year land lease for the incinerator site located adjacent to the canning plant. Under these circumstances it proved difficult to assign a true value to the land in factoring capital costs.

Orlando and Siloam Springs placed a series of contracts for their plant construction, each separating out major items so that costs could be readily identified. Pahokee combined plant, sewer installation, landscaping and driveways into one contract. The cost breakdown of major components is unknown.

The life of the small modular plants is still unknown exactly. However, experience with the type of buildings used would indicate that 20 years is reasonable. The incinerators and steam boiler equipment are estimated to have a useful life of 15 years, though this is yet to be proven. These life cycles have been used in arriving at depreciation figures for calculating total operating costs.

TABLE 24

BREAKDOWN OF 1974 CAPITAL INVESTMENTS

PLANT	PURCHASE PRICE*	ESTIMATED LIFE (YEARS)	ANNUAL DEPRECIATION COST	% OF PURCHASE PRICE
Pahokee				
Plant Bldg. & Fencing with Utilities	$ 57,825	20	2,891	36
Incinerators (2)	103,576	15	6,905	64
TOTAL	$161,401		9,796	100
Design Capacity - 17 tons/10 hr. day				
Cost per ton of Design Capacity	$ 9,494			
Orlando				
Plant Bldg. with Utilities	$263,077	20	13,154	29
Scale House & Office	31,521	20	1,576	3
Incinerators (8)	600,000	15	40,000	66
Fence & Sign	14,798	20	740	2
TOTAL	$909,396		54,730	100
Design Capacity - 100 tons/10 hr. day				
Cost per ton of Design Capacity	$ 9,093			
Siloam Springs				
Plant Bldg., Road & Fence with Utilities	$118,000	20	5,900	32
Incinerators (2)	146,000	15	16,867	68
Energy Recovery Units (2)	107,000			
TOTAL	$371,000		22,767	100
Design Capacity - 21 tons/10 hr. day				
Cost per ton of Design Capacity	$ 17,667			

* The above capital costs represent all labor, materials and installation charges for complete finished construction, as well as the installation of all necessary service utilities. Depreciation is on a straight line basis.

Vehicle Costs

Vehicle requirements are minimal. The most satisfactory plant vehicle is a front-loading tractor with an estimated life of five years. The average cost is $6,000.

TABLE 25

1974 PLANT VEHICLE PURCHASE COSTS

	PURCHASE PRICE	ESTIMATED LIFE (YEARS)	ANNUAL DEPRECIATION COST *
Pahokee			
1 Front Loading Tractor	$ 5,835	5	1,167
Orlando			
3 Front Loading Tractors	$18,000	5	3,600
1 Dump Truck, Used	4,000	5	800
1 Pickup Truck	3,540	5	708
	$25,540		5,108
Siloam Springs			
1 Front Loading Tractor	$ 6,025	5	1,205

* Depreciation is straight line.

Operating Costs

The major operating costs with municipal small incinerators are for labor and auxiliary fuel. The relationship between these two figures varies considerably depending on local cost structures.

Plants using natural gas at present have lower auxiliary fuel costs than those using No. 2 diesel fuel. Pahokee and Orlando are good examples of this differential in the State of Florida. In late 1975, No. 2 diesel oil was selling to Pahokee for a price of 43¢ per gallon, an increase of almost 100 percent in two years. Such oil has a heating value of 138,500 Btu per gallon. Natural gas, on the other hand, was selling to Orlando for $0.13 per therm

(100 cubic feet) which gives a heat production of 97,000 to 103,000 Btu. To convert the purchase prices of the two fuels into a common denominator of Btu output, No. 2 diesel oil currently costs approximately 2.3 times the cost of natural gas, for Btu equivalent output, in the State of Florida. Unfortunately, Pahokee has no access to natural gas and must use oil as its auxiliary fuel.

By October 1975, when the Siloam Springs plant was tested, using natural gas, it was noted that the price per therm had almost doubled in less than a year. It had risen from $0.058 in 1974 to $0.092 in mid 1975 per therm, or 100 cubic feet; still less expensive than central Florida.

Comparing total fuel bills for each plant against the actual tons of waste burned during the past year, we find considerable differences between the three plants in cost of fuel per throughput ton: Pahokee - $8.17; Orlando - $1.24; and Siloam Springs - $0.82.

Labor costs varied considerably between the tested plants, due to base rates and fringe benefits. Also, the staffing patterns differ considerably as can be seen in Table 26.

All of the plants are too new to determine what the actual maintenance costs will be over their life span. Each starts out using a budget figure based on the recommendations of the manufacturers of the incinerators, the buildings and the waste loading vehicles for both preventive and curative maintenance actions. The major item of maintenance in all the plants appears to be the refactory linings of the incinerators that can be damaged through thermal shock and during ash removal. The tubes in the steam boilers may prove an important maintenance item at Siloam Springs.

In an effort to establish accurately projected maintenance costs, the study team made a survey of nine other similar municipal small incinerator plants that had been in constant operation for at least two years. One had been operating five and one-half years with no major replacement of refractory linings and only some minor electric work performed. Three plants had been operating for over three years. One reported it had performed a major repair procedure on the refractory. The other two reported minor thermocouple replacements. The five remaining plants that had been operating up to three years reported, as did all plants, some patching of refractory linings and some minor mechanical and electrical repair. One point made very clear was that refractory repair can be performed in-house, simply and quickly, and at far lower cost than by hiring outside contractors. Further, all plants appear to feel that the manufacturers should provide annual preventive maintenance contracts, as is done with many items of capital equipment.

Using the actual figures from these plants, combined with the first year's experience with the plants under warranty, a projection of these costs indicates that $0.37 per ton of installed capacity for the life of the equipment is a reasonable maintenance figure for the plants with straight incineration. With steam recovery, the figure would appear to be $0.48 per ton of installed capacity. These figures have been used in Table 26. Table 27 shows a slightly higher figure as design capacity and throughput differ.

The Environmental Protection Agency feels that a more realistic maintenance cost may be as high as 5% annually of the original purchase cost. This is based on previous EPA experience with large scale solid waste processing equipment. If this higher annual maintenance cost factor is applied to the figures given in Tables 26 and 27, the annual operating costs would increase per ton by $1.66 at Pahokee, $1.34 at Orlando and $2.93 at Siloam Springs.

The cost of utilities (water, electricity and telephone) appears to vary considerably between the plants - from $130 to $1,000 per month. The electricity used at each plant in KW hours average per month was: Pahokee - 6,213 KW hours; Orlando - 27,100 KW hours; and Siloam Springs - 10,195 KW hours.

Water cost in a straight incinerator plant is low; used for plant clean-up mainly. Pahokee uses a well and does not record or pay for water. Orlando has a representative figure of $90.90 per month. Where steam is produced, and with no condensate return, water and electricity run higher in cost than fuel. This is seen at Siloam Springs, with annual costs of $1,890.00 for water and $4,160.00 for electricity, or $6,050.00 total for the two utilities.

Fuel costs for the front loading vehicles are fairly consistent between the plants and directly related to the equipment used. Supply costs (for chemicals, paints, tools, uniforms, office supplies, vehicle tires and batteries, housekeeping supplies, etc.) are hard to predict exactly over the future years, as new plants are always faced with some abnormal expenditures the first year.

Table 26 summarizes and compares the operating costs for all three plants.

TABLE 26

ANNUAL 1975 OPERATING COSTS

	Pahokee	Orlando	Siloam Springs
1. LABOR			
Plant Supervisor	$ 9,235	$ 16,008	$12,585
Plant Foreman	-	9,876	-
Plant Labor	6,136 (1)	45,276 (6)	11,178 (2)
Secretarial & Office, assigned	4,946	9,040	-
Overtime Pay Total	672	12,284	2,098
Labor Overhead & Fringes	1,202	14,105	2,334
TOTAL DIRECT LABOR & FRINGES	$22,191	$106,588	$28,195
2. AUXILIARY INCINERATOR FUEL*	$31,605	$ 33,317	$ 4,366
3. UTILITIES (Water, Electricity, Telephone)	$ 2,561	$ 10,272	$ 6,350
4. SUPPLIES & SERVICES**	$ 1,833	$ 5,640	$ 3,482
5. MAINTENANCE FUND +	$ 1,635	$ 9,620	$ 3,125
6. VEHICLE FUEL	$ 825	$ 2,340	$ 672
TOTAL EXPENSES	$38,459	$ 61,189	$17,995
TOTAL OPERATING COSTS ‡	$60,650	$167,777	$46,190

*Low fuel costs at Siloam Springs are the result of a newly developed air-fuel control system and lower gas prices than paid by Orlando; both sites show the savings in natural gas prices versus #2 oil as used by Pahokee in 1975.

**Plant, office and vehicle supplies.

+ Maintenance fund is based on $0.37 per design ton charged per year for Pahokee and Orlando and $0.48 at Siloam Springs to plant equipment and incinerator repair.

‡All figures were obtained from the books of account of each municipality.

Comparative Total Costs

When the operating costs and the capital and financing costs are combined into the total annual costs for each plant, complete comparisons can be made between them. These stand out clearly when all items are reduced to the basis of cost per ton processed annually as set forth in Table 27.

Unless a plant approaches its design capacity in the tonnage of waste it processes annually, certain fixed overhead and operating costs cannot be reduced below minimum levels. This is best illustrated at Pahokee with higher unit labor and plant operating costs, as well as higher unit capital costs in comparison with Orlando.

The study team desired to put all three plants on an equal basis for comparison and included interest charges at both Pahokee and Orlando equivalent to the rate being paid by Siloam Springs. As footnoted, neither Pahokee nor Orlando are paying such charges and the true total costs per ton are $18.53 at Pahokee and $8.50 at Orlando.

Steam generating equipment has been expensive in these first plants, as seen from the Siloam Springs unit capital figures, which are more than double those of Orlando. This high capital cost so heavily affects the Siloam Springs unit cost structure that the total gross costs (before steam sales revenues enter the picture) are 61% higher than that of Orlando.

A review of the Siloam Springs "Steam Sale Agreement" (Appendix E) indicates that this situation should change by late 1976. When the figures were assembled late in 1975, steam purchases were beginning to rise. The purchase curve indicates that for the following year, the cannery will purchase approximately 31 million pounds of steam, requiring 434,000 therms of gas at a minimum price of $0.092. This would increase steam sales revenue, reducing operating costs to under $1.20 a ton and reducing total costs to under $8.50 per ton, or fairly close to the total costs at Orlando. Each rise in fuel costs that must be paid by the steam purchaser will reduce total costs further. The prediction is that steam sales will completely offset direct operating costs within two years, based on the curve of rising gas prices.

The serious effect of fuel costs can be seen at Pahokee, with No. 2 oil boosting the fuel unit cost per ton processed to almost seven times that of Orlando and almost ten times that of Siloam Springs, both of which use gas. Admittedly, under-utilization and less sophisticated controls at Pahokee contribute to this. The difference a control system can make on fuel costs can be seen in comparing Siloam Springs and Orlando.

Detailed examination of the books and records of each plant revealed considerable differences in accounting methods, in the establishment of cost centers and cost accounting, in general. As stated earlier in this report, it is essential to weigh all incoming waste and possibly outgoing residue to keep track of the efficiency of the operation and as a major basis for cost control. As fuel, electricity and water usage affect operating costs, as well as knowledge of whether the efficiency level of the incinerators is being maintained, it is imperative to have accurate flow meters installed and to read them constantly.

When steam sales are being made, accurate pressure and recording/totalizing flow meters should be installed at the steam outlet, adjacent to the boilers, to prove, conclusively, the pressure and poundage of steam being delivered to customers. Such meters must be maintained regularly to ensure accurate records.

Virtually every operation and record ties into throughput tons of waste on a daily, weekly and monthly basis, and cost control should be set upon this basis. Fluctuations in cost will often reveal the need for preventive or corrective maintenance or variations in labor output. Cost accounting should always set up maintenance labor, supplies and services in a separate center to ensure that all costs are being properly charged to this function rather than included with other operating accounts.

Finally, monthly summary reports to management, by cost center, prove helpful if corrective action is required.

TABLE 27

COMPARATIVE ANNUAL OPERATING COSTS FY 1974-75

	PAHOKEE		ORLANDO		SILOAM SPRINGS	
TOTAL TONS PROCESSED PER YEAR		3,864 (13.8 x 260)		26,780 (103 x 260)		5,270 (17 x 310)
	$ TOTAL	$ PER TON PROCESSED	$ TOTAL	$ PER TON PROCESSED	$ TOTAL	$ PER TON PROCESSED
OPERATING COSTS						
Labor	22,191	5.74	106,588	3.98	28,195	5.35
Auxiliary Fuel	31,605	8.17	33,317	1.24	4,366	.82
Utilities	2,561	.66	10,272	.38	6,350	1.20
Supplies & Services	1,833	.47	5,640	.21	3,482	.66
Maintenance	1,635	.42	9,620	.36	3,125	.59
Vehicle Fuel	825	.21	2,340	.09	672	.13
TOTAL OPERATING COST, GROSS	60,650	15.69	167,777	6.26	46,190	8.75
ENERGY SALE REVENUE	-	-	-	-	32,000*	6.07
TOTAL OPERATING COST, NET					14,190	2.68
FINANCING & OWNERSHIP COSTS						
Plant Depreciation	9,796	2.54	54,730	2.04	22,767	4.32
Vehicle Depreciation	1,167	.30	5,108	.20	1,205	.23
Interest (16 yr. 5.89% bonds)	6,259 **	1.62	35,662 **	1.33	14,556	2.76
TOTAL FINANCING & OWNERSHIP COST	17,222	4.46	95,500	3.57	38,528	7.31
TOTAL ANNUAL COST, GROSS	77,872	20.15	263,277	9.83	84,718	16.06
NET					52,718	9.99

Disposal charges are not included in any plant due to proximity and ownership of landfill at each.

* Siloam Springs operating revenue is based on minimum revenue under the Steam Sales Agreement @ $0.092/therm

** A theoretical interest rate of 5.89% is used to make costs comparable with Siloam Springs. In actuality, there is no interest cost as cash from available municipal funds was used for the entire capital purchase.

CHAPTER 14

STEAM PRODUCTION FROM SMALL INCINERATORS

The investigation of resource recovery has followed many paths in recent years. Several major experiments deal with the removal and sale of metals, paper products and glass from the waste stream. With the continued shortfall of fossil fuels and steadily rising prices, considerable attention has been placed on municipal waste as a source of energy and a substitute for coal, oil or gas. The conversion of solid waste into combustible oil or gas by pyrolysis is being studied for economic feasibility. In direct energy production from incineration, at least three steam producing designs have emerged. Milled combustibles in the solid waste stream have been used to augment the fuel in conventional coal-fired boilers, used to produce steam for turbine generation of electricity. Waterwall incineration has been installed in a few large plants, producing steam from the waste heat in the primary chamber for the generation of electricity. Controlled air incinerators utilize afterburner gases.

Most proposals and ongoing experiments seem to envision mass production. Waste from large cities and their surrounding suburbs is to be transported into a processing plant of 300 to over 1,000 tons a day capacity, to take advantage of economics of scale. This mass production approach seems to ignore some important points.

The United States has 15 times as many towns of 8,000 to 200,000 population, generating small to medium tonnages of municipal waste, as it has large cities of over 200,000. The most expensive aspects of waste management in 1975 are collection and transportation costs, and the wider the area covered the higher the costs. Industry is dispersed to a tremendous extent through the smaller cities. When we examine resource recovery in the form of steam production from waste, we see that much of this industry needs energy to survive, but in relatively small unit quantities. In short, if we look at municipal waste management as a completely engineered regional economic system, there remains the question of the practical economies of size.

Based on the experiemts that have been conducted for producing steam from municipal waste, it would appear that the mass production plants, as currently designed, do not have practical cost advantages. With mechanized facilities, automated handling equipment and air pollution control devices installed, their cost per ton of designed capacity is as high or higher than the small incinerator modular plants. Even though they do not use auxiliary fuel, they do not appear to be able to process waste on a total cost per ton basis any cheaper than the efficient modular plants. When total ownership cost per ton processed is added, they are often more expensive than the modular small incinerator plants.

The raw fuel material, solid waste, can be delivered to the small plants relatively inexpensively. The smaller plant can be constructed near sources generating medium quantities of waste and still operate fairly economically, whereas, the mass production plant must pay hauling and transfer costs as high as $10.00 per ton in 1975 to obtain needed quantities to match its capacity.

Chapter 4 discussed the technical and corrosion problems of steam production from waste in utility company boilers or in conventional "water-wall" incinerators. From this point alone, unless the mass production units considerably improve their engineering basis, and at an installed cost per ton of capacity equal or lower than that of the modular units, the small controlled air incinerators, producing less contaminated gases, appear to have an advantage.

The mass production plants lack the flexibility and simplicity of design that might be needed for expansion compared to the modular plants. They also are faced with much more rigid site selection criteria because of their size, complexity, and heavy vehicle traffic.

To date, the mass production plants have turned out a more flexible end product. The steam they produce is normally planned as a first step - the final product is electric power. Electricity can be delivered in wires over a wide area inexpensively, while the modular plant, with its limited capacity practically must produce steam to be used as steam; delivered in pipes to customers relatively close to the plant.

The potential for modular small incinerator plants producing steam for local industrial or institutional needs appears to have become a reality during the past year. If the developments continue at the present rate, this method offers an impressive energy alternative for hundreds of communities and their steam-using industries. It also offers the possibility for a larger city to be divided into incinerator plant zones, compact in size to reduce hauling costs, supplying steam to local industry or institutions.

The Impact on the U. S. Energy Needs

Based on the present efficiency of the controlled-air incinerator gas boilers, and the known averages of heat production from municipal waste, certain parameters and constraints apply when considering the use of this method for producing steam.

Municipal waste is not as efficient a fuel as any of the fossil fuels. It has a lower Btu output per pound in its average "as received" condition: greater weights must be burned to produce the energy equivalent of coal, oil or gas. The heat output of municipal waste "as received" averages 5,000 Btu/lb. This is one-half to one-third that of coal which ranges from 10,550 to 14,000 Btu/lb. A pound of #2 oil releases four times the energy of the equivalent weight of municipal waste. It has not the compactness of fossil fuel and far greater volumes must be burned to reach equivalent energy output. Oil measures 31 to 35 cubic feet per ton; coal measures 45 to 50 cubic feet per ton. Municipal waste usually ranges in density, in its "as received" condition, from 130 to 400 cubic feet per ton. However, it also contains by weight up to 30% moisture and up to 30% non-combustibles, neither of which contributes to the release of energy. The combustible portion has densities as low as 650 cubic feet per ton.

Designers of waste-heat recovery systems have accepted these ratios. The materials handling equipment and the engineering of combustion systems provide for the lower densities and larger volumes of fuel (solid waste) that must be charged to produce satisfactory energy recovery.

When we consider controlled air incinerators, the contribution of auxiliary fuel to the production of steam must be considerably less than the fuel used in a direct-fired boiler. The burning waste must supply the bulk of the energy, so that there are important net savings in fossil fuels. Further, the gas emissions reaching the boiler tubes must be as uncontaminated as possible to reduce corrosive effects and coating of the tubes. Emission levels from the stack must remain within acceptable limits.

It requires, theoretically, 1,000,000 Btu from the fuel being burned to produce 1,000 pounds of steam. Most boilers are only 70 to 75 percent efficient in transforming this heat and 1,400,000 Btu must be produced by the fuel to obtain 1,000 pounds of steam. Natural gas has a theoretical heating value of 100,000 Btu per 100 cubic feet. Ratings can be as low as 97,000 Btu. No. 2 diesel oil will average 138,500 Btu per gallon.

Hence, the fuel required in the average 70% efficient boiler to produce 1,000 pounds of steam would be approximately 1440 cubic feet of natural gas, or 10 gallons of No. 2 diesel oil; and from 250 to 500 pounds of waste.

There are 2500 communities in the United States with populations between 8,000 and 100,000 that have industrial plants requiring steam. There are another 85 communities between 100,000 and 200,000, and a further 160 communities over 200,000 in size, all of which have industry requiring steam.

It is estimated that these urban areas have a daily total waste generation, six days a week, of 425,000 tons. If this averaged 5,000 Btu/lb, the total energy contained would be four trillion, 250 billion Btu; which could produce 2.975 billion pounds of steam at average efficiency.

If all this waste was burned to produce this amount of steam in the controlled air design incinerators of the efficiency studied at Siloam Springs, in place of natural gas or oil, the net savings in these fossil fuels, after deducting the auxiliary fuel requirements, are in the order of 4.115 billion cubic feet of gas per day. The savings in No. 2 diesel oil would be 29.1 million gallons daily.

Despite these impressive figures, both the modular small incinerator plant producing steam as the end product, and the large incinerator-boiler producing steam for generating electricity, are merely auxiliaries. They will never process enough waste to meet the nation's requirements for industrial steam or electricity. However, they can contribute greatly to our shortfall situation. Further, they may lead to the most feasible method for processing a large proportion of the nation's solid waste stream.

In the final analysis they must produce steam that is satisfactory to many diverse customers and it must be sold on an equitable basis. Some experimental plants give indications that such marketing can be achieved now, if the proper combination of designer, builder, municipality, financial packaging and energy buyer are assembled.

CHAPTER 15

SILOAM SPRINGS STEAM PRODUCTION

The Siloam Springs, Arkansas plant was selected as an example of the engineering state of the art in 1975 for waste-heat recovery and steam production. Five days of testing showed that the system and plant operated effectively for the purpose intended, while accepting average municipal waste without any prior treatment.

Tables 15 through 18 show that stack emissions were acceptable and, in fact, considerably below the levels of the two other tested plants which did not have the waste heat recovery feature.

The life of the boiler tubes and the effect of corrosive or coating chemicals in the waste gases cannot be proven definitely, as the plant has been operating for less than a year. However, based on visual inspection of the tubes, the automatic tube cleaning system appears to be working efficiently.

An important determination during testing concerned the efficiency of steam production in pounds per hour at 100 psig, compared to the Btu value of the charged waste, combined with the use of auxiliary fuel. Waste was charged during the test period for up to seven hours a day, while auxiliary fuel was used over a period of 10.5 hours, including the warm-up and burn down periods.

Table 28 shows the steam produced per hour during waste charging, as well as the total steam produced during a typical 10.5 hour day with auxiliary fuel being burned. It shows the pounds of waste burned for the total period and the auxiliary fuel used during three operating modes and in total. Table 29 analyzes and compares this data to show the pounds of steam produced for each pound of waste burned, along with the amount of auxiliary fuel consumed for each pound of steam produced. It then compares this method of producing steam with the use of a direct fired boiler, operating at 70% efficiency, to show the amount of fossil fuel that is saved by using the solid waste as the principal source of energy for the steam production.

TABLE 28

STEAM PRODUCTION AND FUEL CONSUMPTION SILOAM SPRINGS

Operating Period	Steam Produced	Waste Burned	Auxiliary Fuel Consumption (Cu. Ft. Gas)
Warm-up (1/3 hr.)	none		880
Charging (7 hrs.)	4,795 lbs./hr.		1560
Burn-down (3 hrs.)	4,620 lbs./hr.		1170
Total (10 1/2 hrs. Period)	47,425	16,696	3610

Average Steam Pressure at Boiler....100 psig.

TABLE 29

TOTAL STEAM PRODUCTION FUEL SAVINGS ANALYSIS

Steam Produced (pounds) per boiler per day	47,425
Pounds of Steam Produced per Pound of Waste Burned	2.84
Cubic Feet of Auxiliary fuel Consumed per Pound of Steam Produced	0.076
Cubic Feet of Gas Saved per Pound of Steam Produced, Compared to a Direct Fired Boiler Operating at 70% Efficiency	1.43
Value of Siloam Springs natural gas	970 Btu/ft^3

There would be a further savings in fuel, not revealed by these figures, if the system utilized a condensate return, as would normally be found in closed boiler systems. All feed water at Siloam Springs is fresh and energy is required to raise it from the incoming temperature of around 50°F to the temperature of 338°F at which the steam is produced. Despite this, at a production of 47,425 pounds of steam, the savings of natural gas over a direct fired boiler were 66,774 cubic feet. At the current Siloam Springs price of $0.092 per 100 cubic feet (one therm), this amounts to $61.43 savings per day over the purchase of fuel to produce this amount of steam in a direct-fired boiler.

The next point investigated was the operating efficiency of the waste heat boiler, based on the total Btu input from both the solid waste and the auxiliary fuel, compared to the total steam produced. The Btu value of the charged waste is extremely important in such an analysis. Unfortunately, without extremely sophisticated test equipment it is impossible to determine this value on a charge by charge basis. The laboratory analysis of the average waste was used. As seen from Table 19, the net average value on an "as received" basis, amounted to 4,353 Btu/pound.

Calculating the efficiency of a direct-fired boiler, using a fuel with a constant Btu output, is obviously simpler than calculating the efficiency of waste-heat boilers. The heat transfer comes from burning a product that continually varies in Btu value. In the type of controlled air incinerator tested at Siloam Springs, the use of auxiliary fuel and air is designed to compensate for these variations and control the temperature level in the gas passing around the boiler tubes.

From a practical viewpoint, efficiency calculations can only use averages in dealing with such waste-heat boilers. The assumption is made that the waste does average out at a given Btu/pound figure.

Table 30 shows how boiler efficiency at Siloam Springs can be estimated under one method. The total potential Btu output of the waste, coupled with the output of the auxiliary fuel, is calculated. The total steam production is measured and the theoretical energy that would be required to achieve this production is then calculated. The two figures are compared to determine the boiler efficiency.

TABLE 30

BOILER EFFICIENCY ANALYSIS - SILOAM SPRINGS

Waste Burned....................16,696 pounds

Heat Potential @4353 Btu/pound "as received"...........72.7 million Btu

Auxiliary Gas Consumed........... 3,610 cu. ft.

Heat Potential @ 970 Btu/cu. ft. .... 3.5 million Btu

Total Heating Potential 76.2 million Btu

Feedwater Inlet Temperature - 50°F

100 psig Steam Temperature - 338°F

Energy to raise 50°F to 338°F -	291 Btu/lb.
Energy to produce steam @ 338°F -	881 Btu/lb.
Total Energy Requirement	1,172 Btu/lb.

Energy requirement for 47,425 pounds of steam..........55.5 million Btu

Theoretical Boiler Efficiency...........72.8%

Only considerable additional field testing of these systems will definitely establish the total amount of steam they are capable of producing from wastes of varying heat values, and hence the amount of direct-fired boiler fossil fuels that they will save. With condensate return systems incorporated, along with satisfactory automatic ash removal systems, the rate of efficiency would climb further.

The pounds per hour of steam produced will vary with the design and efficiency of the incinerator waste-heat boiler system. It will also vary with the average Btu values of the waste as charged and the weight charged per hour. Figure 19 illustrates these heat value-charging weight relationships.

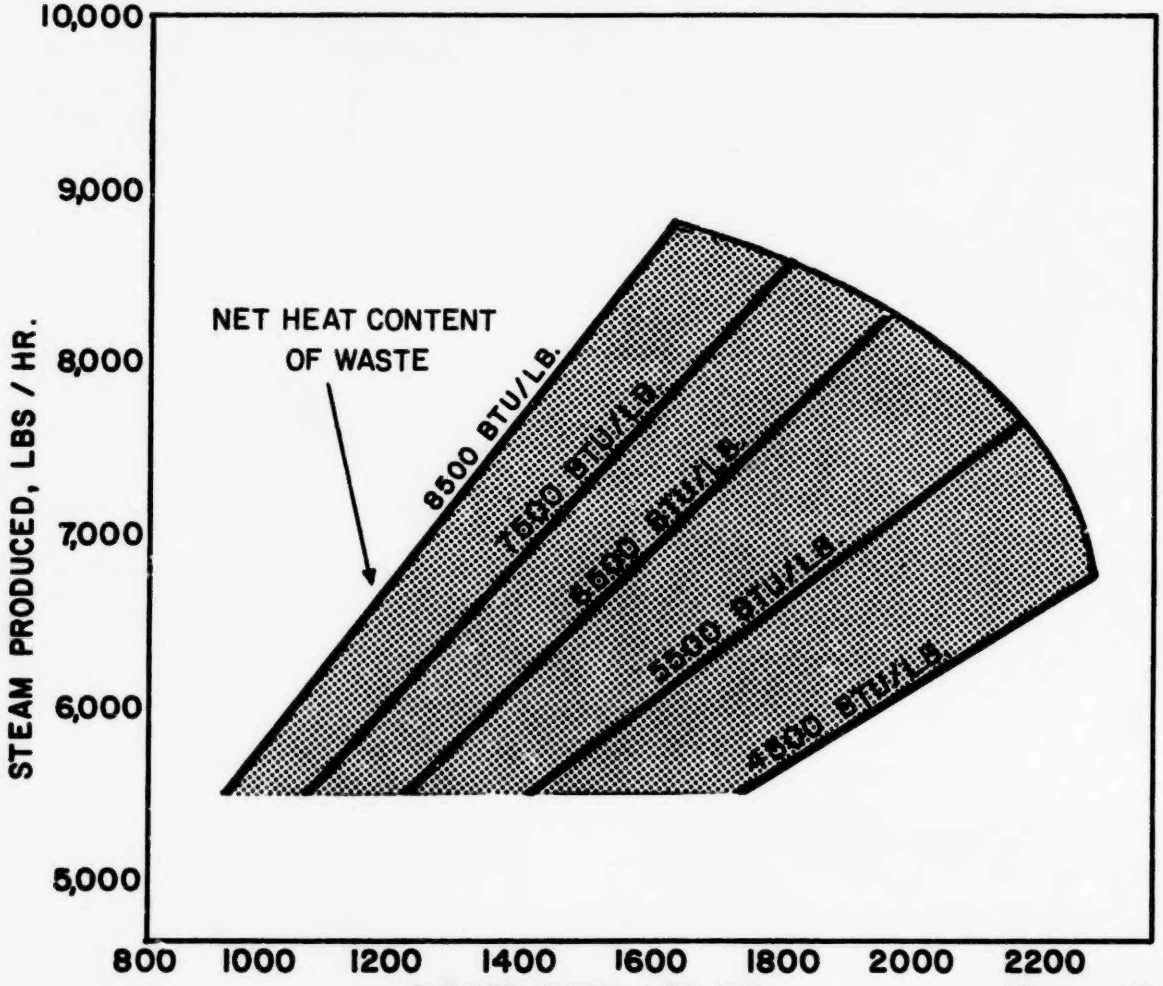


Figure 19

STEAM PRODUCTION BASED ON WASTE HEAT OUTPUT AND CHARGING RATES.

FOOTNOTE REFERENCES

1. Federal Register, December 23, 1971.

2. *Present Status of Municipal Refuse Incinerators*, American Society of Mechanical Engineers, January 1975.

3. Achinger, W. C. and Daniels, L. E., *An Evaluation of Seven Incinerators*, 1970 National Incinerator Conference.

4. Achinger, W. C. and Daniels, L. E., *An Evaluation of Seven Incinerators*, 1970 National Incinerator Conference.

5. EPA, Office of Solid Waste Management, *Municipal-Scale Thermal Processing of Solid Waste*, EPA Contract 68-03-0293, Recon Systems, Inc., December 1975.

6. EPA, Office of Solid Waste Management, *Municipal-Scale Thermal Processing of Solid Waste*, EPA Contract 68-03-0293, Recon Systems, Inc., December 1975.

APPENDIX A

FIELD TEST REPORTS

Form #1

INCOMING SOLID WASTE WEIGHTS

PLANT ________________________ PAGE ____ OF ________

ORGANIZATION ________________ RECORDED BY ________________

Truck No.	Date	Gross Weight of Truck and Waste (lb)	Truck Tare Weight (lb)	Net Weight of Waste (lb)	Hour of Day Delivered
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Total					
AVERAGE					

Comments:

Form #2

INCOMING SOLID WASTE BULK DENSITY DETERMINATION

PLANT ______________________________ PAGE ___ OF ________

ORGANIZATION ____________________ RECORDED BY ____________________

Container No.	Date	Dimensions of Container (inches) H x L x W	Cubic Feet of Waste	Gross Weight of Container & Waste (lb)	Container Tare Wt. (lb)	Net Weight of Waste (lb)	Bulk Density of Waste (lb/cu-ft)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
Average							

Comments:

FORM NO. 3
PAGE OF

CHARGING RATE & OPERATING DATA

PLANT ______________________ DATE ______________________
ORGANIZATION ______________________ RECORDED BY ______________________
TOTAL WEIGHT CHARGED(LBS) __________ NO. OF CHARGES ______________________
TOTAL CHARGING TIME(HRS) __________ TOTAL COMPLETE BURN TIME(HRS) __________

TIME OF CHARGE	FUEL CONSUMPTION METER READINGS		GAS ☐ OIL ☐	INCINERATOR INTERIOR TEMP. DEGREES F.		BOILER PRESSURE	STEAM LBS/HOUR
	LOWER	UPPER	TOTAL	LOWER	UPPER		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

FINISH			
START			
TOTAL			

POWER ANALYSIS:
Meter Reading end of Day ____________ KWH
Meter Reading Beginning ____________ KWH
Power Consumed/Period ____________ KWH

WATER ANALYSIS:
Meter Reading end of Day ____________ GPH
Meter Reading Beginning ____________ GPH
Water Consumed/Period ____________ GPH

Form #4

INCOMING SOLID WASTE COMPOSITION DATA
FIELD SAMPLE

PLANT ______________________ DATE ____________

SAMPLE NO. ______________________ TIME ____________

ORGANIZATION ______________________ ANALYZED BY ____________

Category or Component	Gross Weight of Container & Waste * (lb & oz)	Container Tare Weight (lb & oz)	As Received Weight Net (lb & oz)	As Received Percentage
COMBUSTIBLES				
Food Waste				
Garden Waste				
Paper Products				
Plastics, Rubber leather				
Textiles				
Wood				
Fines				
NONCOMBUSTIBLES				
Metals				
Glass, Ceramics				
Ash, Dirt, Rocks				
TOTAL				100.0

*Triple wrapped plastic bags

COMMENTS:

Form #5

INCOMING SOLID WASTE COMPOSITION DATA

LABORATORY SAMPLE

PLANT ______________________________ DATE ________________

SAMPLE NO. __________________________ TIME ________________

ORGANIZATION _______________________ ANALYZED BY ________________

Category or Component	As Received Weight (lb & oz) Gross Wgt.	Container Tare Wgt.	Net Wgt.	As Received Percentage of Net
COMBUSTIBLES				
Food Waste				
Garden Waste				
Paper Products				
Plastics, rubber leather				
Textiles				
Wood				
Smalls				
Fines				
NONCOMBUSTIBLES				
Metals				
Glass, ceramics				
Ash, dirt, rocks				
TOTAL SAMPLE			20 lb-0oz.	100.0

COMMENTS:

Form #6

RESIDUE BULK SAMPLE DETERMINATION

FIELD DATA AND CALCULATIONS

PLANT ______________________________

ORGANIZATION ____________________ RECORDED BY ____________________

Sample No.	Date	Dimensions of Container (inches) H x L x W	Cubic Feet of Residue	Gross Weight of Container & Residue (lb)	Container Tare Weight (lb)	Net Weight of Residue (lb)	Bulk Density (lb/cu-ft)
1							
2							
3							
4							
5							
Average							

Comments:

Form #7

RESIDUE DETERMINATION

LABORATORY SAMPLE

PLANT ____

ORGANIZATION ____________________ RECORDED BY ____________________

Sample No.	Date	Dimensions of Container (inches) H x L x W	Cubic Feet of Container	Gross Weight of Container & Residue (lb)	Container Tare Weight (lb)	Net Weight of Residue (lb)
1						
2						
3						
4						
5						
TOTAL						

Comments:

Form #8

WASTE/TO RESIDUE REDUCTIONS

PLANT ____________________

ORGANIZATION ____________________ CALCULATIONS ____________________

WEIGHT REDUCTION

Sample No.	Date	Total Raw Weight of Waste	Total Weight of Residue	Difference	Residue % Raw Waste	% of Reduction of Raw Weight
1						
2						
3						
4						
5						
Total						
Average						

VOLUME REDUCTION

Sample No.	Date	Raw Weight Waste	Avg. Lbs/ Cu.ft. Waste	Total Cu.ft. Waste	Cu.ft. of Total Residue	Dif- ference	Residue % Raw Cube	% of Reduction of Raw Cube
1								
2								
3								
4								
5								
Total								
Average								

APPENDIX B

LOWER HEATING VALUES OF TYPICAL WASTES

PRODUCT	BTU/LB NET
Agricultural:	
Butter	15,240
Cotton Seed Hulls	7,910
Grain	7,130
Egg Yolk	13,400
Egg White	9,440
Pecan Shells	8,100
Garbage:	
Coffee Grounds	9,800
Corn Cobs	7,540
Corn, Shelled	8,550
Fats	15,360
Food Wastes(Dry)	7,800
Paper Products:	
Brown Paper	7,090
Corrugated Boxes	6,830
Food Cartons	7,110
Magazines	4,830
Newspapers	7,800
Plastic Coated Paper	7,090
Tar Paper(30% Tar)	10,120
Waxed Milk Cartons -	10,790
Plastics:	
Polyamides(Nylon)	11,960
Polyesters	11,050
Polyolefins(Polyethlene, Polyproplene, etc.)	17,500
Polystyrene	15,650
Polyurethane	10,580
Polyvinyl Chloride	7,280
Plastic Film(Mixed)	12,740
Vinyl Coated Fabric	8,200
Vinyl Coated Felt	10,170
Vinyl Scrap	10,500
Rubber Products:	
Latex	9,200
Banbury-Rubber Scrap	12,180
Raw Batch Stock	13,040
Rubber Coated Fabric	10,120
Rubber Tape	8,860
Rubber Tires	12,000
Textiles:	
Cotton Batting	6,540
Uncured Duck	8,600
Rayon and Cotton Yarn	7,138
Rags	7,390
Wood:	
Oak	7,990
Pine	8,420
Sawdust	8,000
Yard:	
Brush	7,270
Grass	7,070
Leaves	6,530
Miscellaneous:	
Paints and Oils	12,330
Leather	8,140
Linoleum	7,700
Street Sweepings	5,520
Water	(1,000) Minus

APPENDIX C

STACK EMISSION TESTING DATA

EMISSIONS TEST PAHOKEE, FLORIDA INCINERATOR

	Trial Run Date	Test Run No. & Date		
		1	2	3
	5/12/75	5/13/75	5/14/75	5/15/75
1. Dry Catch (Probe+ Filter), Grams	.3484	.2558	.2898	.2558
2. Cond. Catch (Impingers), Grams	.0118	.0467	.0553	.0276
3. Barometric Press. Mean Sea Level	29.97	30.00	29.98	29.96
4. Stack Pressure, IN W.G.	.05	.05	.02	.02
Absolute in Mercury	29.96	29.99	29.97	29.95
5. Avg. Meter Temp., Deg. F	106	105	107	110
6. Total # Traverse Points	48	48	48	48
7. Total Test Duration, Min.	240	270	260	263
8. Meter Conditions, Dry Gas Sampled (Cu. ft.)	129.047	138.499	126.308	121.060
Total cu. ft. (gas) Sampled	136.402	156.728	145.786	139.858
Total cu. ft. (gas) in Stack	335.22	405.325	354.704	353.517
Std. cu. ft. Dry Gas Sampled	120.839	129.821	118.116	112.536
9. Molecular Wgt. of Condensate	18	18	18	18
10. PITOT Correction Factor	.85	.85	.85	.85

Stack Cross Sectional Area, Sq. Ft. - 8.080

Stack Height above Ground Level, Ft. - 40

STACK EMISSION TESTING DATA

EMISSIONS TEST ORLANDO, FLORIDA INCINERATOR

	Trial Run Date	Test Run No. & Date		
		1	2	3
	5/19/75	5/20/75	5/21/75	5/22/75
1. Dry Catch (Probe + Filter), Grams	.3466	.4323	.5375	.7524
2. Cond. Catch(Impingers), Grams	.0177	.0265	.0196	.0387
3. Barometric Press. Mean Sea Level	29.99	30.02	30.04	30.05
4. Stack Pressure, IN W.G.	.03	.03	.03	.03
Absolute in Mercury	29.97	30.00	30.02	30.03
5. Avg. Meter Temp., Deg F	104	108	97	100
6. Total # Traverse Points	48	48	48	48
7. Total Test Duration, Min.	279	240	275	240
8. Meter Conditions, Dry Gas Sampled (cu. ft.)	163.381	158.672	167.850	164.232
Total cu. ft. (gas) Sampled	185.031	181.131	195.959	193.395
Total cu. ft. (gas) in Stack	428.565	463.467	520.518	530.483
Std. cu. ft. Dry Gas Sampled	153.492	147.975	159.799	155.333
9. Molecular Wgt. of Condensate	18	18	18	18
10. PITOT Correction Factor	.85	.85	.85	.85

Stack Cross Sectional Area, Sq. Ft. - 8.510

Stack Hgt. Above Ground Level, Ft. - 50

STACK EMISSION TESTING DATA

EMISSIONS TEST SILOAM SPRINGS, ARKANSAS INCINERATOR

	Trial Run Date	Test Run No. & Date		
		1	2	3
	10/2/75	10/3/75	10/3/75	10/4/75
1. Dry Catch (Probe + Filter), Grams	.0315	.0310	.0547	.1072
2. Cond. Catch (Impingers), Grams	.0950	.0467	.0494	.0297
3. Barometric Press. Mean Sea Level	30.15	30.12	30.15	30.00
4. Stack Pressure, IN W.G.	.12	.12	.12	.05
Absolute in Mercury	29.66	29.65	29.68	29.52
5. Avg. Meter Temp., Deg. F.	84	78	95	72
6. Total # Traverse Points	48	48	48	48
7. Total Test Duration, Min.	144	152	150	152
8. Meter Conditions, Dry Gas Sampled (Cu. ft.)	63.655	68.366	89.977	81.580
Total cu. ft. (gas) Sampled	67,437	74,133	95.636	85.454
Total cu. ft. (gas) in Stack	89.935	100.882	123.132	287.805
Std. cu. ft. Dry Gas Sampled	62.041	67.296	85.959	81.221
9. Molecular Wgt. of Condensate	18	18	18	18
10. PITOT Correction Factor	.35	.35	.35	.35

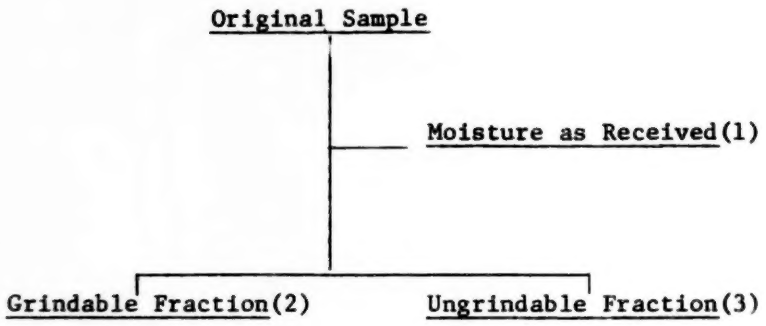
Stack Cross Sectional Area, Sq. Ft. - 3.547

Stack Height above Ground Level, Ft. - 60

APPENDIX D

LABORATORY ANALYSES FORMULAS FOR ALL SITES

Flow Chart of Sample Preparation


Original Sample
Moisture as Received(1)
Grindable Fraction(2)
Ungrindable Fraction(3)

Ash
BUT/lb
Carbon
Hydrogen
Chloride
Fixed Carbon
Nitrogen
Oxygen
Sulfur
Volatile Matter

(1) The moisture as received is on the entire sample.

(2) Results are on the grindable portion of the sample only.

(3) The non-grindable sub-sample that was not incorporated consisted of metals and ceramics that could not pass through grinding mills. This could be considered as part of the ash.

METHOD REFERENCES FOR SOLID WASTE & RESIDUE LABORATORY ANALYSES

ASH
ASTM D-271 Ash in Raw Refuse

BTU/LB
Parr Instrument Co., Instrument Manual, Method # 139

CARBON
ASTM Gaseous Fuels Coal and Coke D271, PP.22-25 (1971)

CHLORIDE
ASTM D2361-66

FIXED CARBON
ASTM Gaseous Fuels, Coal and Coke PP.22-25 (1971)

HYDROGEN
ASTM Gaseous Fuels, Coal and Coke, PP.22-25 (1971)

NITROGEN
ADAC 2.049* Modified

MOISTURE AS RECEIVED
ASTM D271 Moisture in Raw Refuse

MOISTURE AT ASSAY
ASTM P.271 Moisture & Volatile Solids in Raw Refuse

OXYGEN
ASTM Gaseous Fuels Coal and Coke, PP.22-25 (1971)

SULFUR
ASTM D 271-46, Vol. III-A, PP. 36-37

VOLATILE MATTER
ASTM D-271 P.16 (1971

ADAC Methods -11th ED (1970) Except Those Noted * Which are From 12th ED (1975)
ADCS Methods From 3RD Edition (1969)

APPENDIX E

SILOAM SPRINGS STEAM SALES AGREEMENT

AGREEMENT between the City of Siloam Springs, Arkansas, a municipal corporation organized and existing under the laws of the State of Arkansas (hereinafter referred to as the "City"), and the Allen Canning Company, an Arkansas corporation, having a food processing facility located at Siloam Springs, Arkansas, (hereinafter referred to as "Allen").

WITNESSETH:

The City is in the process of purchasing from U.S. Recycle Corp., of Little Rock, Arkansas, a MUNICIPAL WASTE DISPOSAL SYSTEM capable of disposing of 16 tons per 10-hour day of typical municipal refuse, including residential, commercial and industrial, which is to include the following standard equipment:

Two (2) Model C-550M CONSUMAT Systems with Loaders

In addition to the above-specified municipal waste disposal system, the City is in the process of purchasing from U. S. Recycle Corp., a separate ENERGY CONVERSION SYSTEM capable of supplying certain steam energy requirements of Allen's food processing facility located at 1020 East Jefferson Street, Siloam Springs, Arkansas, said energy conversion system to include the following:

ENERGY CONVERSION SYSTEM: This system will utilize two (2) Wast Heat Boilers, Four (4) modules each, Model CR5-504, as produced by Riley-Beaird, Inc., of Shreveport, Louisiana, attached to the two (2) CONSUMAT Model C-550M's as described above.

In consideration of the foregoing premises and the mutual agreements hereinafter set forth, the parties agree as follows:

Section 1: Construction of System

1.1 The City will lease from Allen, the necessary land adjacent to Allen's in-town plant, pursuant to a certain Lease Agreement between the same parties hereto, dated the 11th day of December 1974, a copy of which is attached hereto, and this Energy Agreement and said Lease Agreement are hereby incorporated by reference into and made a part of each separate agreement so that performance by the parties of one agreement shall be contingent upon performance by the parties of the other agreement. The City agrees to purchase, or provide the funds required for the purchase of, the necessary building, waste disposal and energy conversion equipment, as hereinabove specified, at no cost to Allen, in order to produce steam energy through the incineration of solid waste, and to deliver such steam energy to a single interface at a point on Allen's property to be mutually selected by both parties hereto. The plans and specifications for such waste disposal and energy conversion system, approved by the City, are on file in the office of the City Clerk, and are made a part hereof by reference as fully as if written out in toto in this Section of this Agreement. The City will transport such steam energy to said point of delivery and tie into Allen's main steam line at a point on Allen's steam grid system; and, further, the City will furnish, at no cost to Allen, all appropriate pipes, lines, returns and other appurtenances required for such transport.

1.2 The City agrees, at its expense, to construct or have constructed and maintain said waste disposal and energy conversion system in accordance with the requirements of all municipal, state or federal regulations or requirements, with such provisions for fire protection that Allen's fire insurance rating will not be affected, and in accordance with the plans and specifications referenced in Section 1.1 hereinabove. If construction of said system shall result in any increase in fire insurance premiums for Allen, the City shall pay any such increase in premiums.

1.3 The City shall complete construction of such system with due diligence, subject only to delays caused by shortages of labor and materials, government regulations, strikes or any other acts beyond the reasonable control of the City.

1.4 The installations to the point of delivery made by the City at no cost to Allen, pursuant to Section 1.1 hereinabove for the use of steam energy at Allen's facility are to remain the property of the City, even after termination of this Agreement, although connected to, but not a part of, Allen's steam grid system. Upon removal of same by the City, it will restore the interconnection of Allen's steam grid system.

Section 2: Terms of Purchase and Sale

2.1 Allen agrees to purchase from the City all the steam energy produced by the City up to the maximum steam energy requirements of Allen's said food processing facility for a period of twenty (20) years, commencing on the date of the City's first delivery of such steam energy to Allen pursuant to

Section 1.1 hereinabove. The steam energy so generated by the City and delivered to Allen as herein provided shall be for the sole use of Allen and may not be resold by Allen without the express prior written consent of the City. The City reserves the right to sell any excess steam produced by the energy conversion system over and above Allen's maximum requirements, and not purchased by Allen, to others if it so desires.

2.2 The City will make available to Allen at the aforesaid interface at least 120,000 pounds of saturated steam at a minimum of 100 pounds pressure per square inch gauge (PSIG) and up to a maximum of 150 PSIG within a 12-hour period per day for a minimum of 240 days per year during said period of twenty (20) years. The quality of the steam will meet all requirements now existing or hereafter adopted of all local, state and federal governments and other regulatory agencies, for food processing plants.

Section 3: Payment Rates and Terms

3.1 The steam energy provided by the City to Allen pursuant to the Agreement will be measured by an orifice-type vapor flow meter at the point of entry into Allen's steam grid system.

3.2 Allen will pay to the City for all such steam energy consumed the sum of eight and one-half cents ($.085) per 100 pounds of saturated steam between 100 and 150 PSIG measured at said point of entry. The sum is to be calculated upon the basis of natural gas available to Allen at the price of sixty cents ($.60) per m.c.f. Further, it will be increased or decreased in direct proportion to any increases or decreases in such price of natural gas available to Allen, effective the first day of the month following the gas price change. Discounts will be given to Allen on the purchase of steam energy under the following conditions:

3.2.1 As the price of natural gas increases above sixty cents ($.60) per m.c.f., the price of steam will be discounted as in the table below:

GAS PRICE PER M.C.F.	STEAM PRICE PER 100 POUNDS	DISCOUNT	DISCOUNTED STEAM PRICE PER 100 POUNDS
$ 0.60	$ 0.085	0%	$ 0.085
0.70	0.099	4%	0.095
0.80	0.114	8%	0.105
0.90	0.128	12%	0.113
1.00	0.142	15%	0.121
1.10	0.156	17%	0.129
1.20	0.170	19%	0.138
1.30	0.185	21%	0.146

GAS PRICE PER M.C.F.	STEAM PRICE PER 100 POUNDS	DISCOUNT	DISCOUNTED STEAM PRICE PER 100 POUNDS
$ 1.40	$ 0.100	23%	$ 0.153
1.50	0.213	24%	0.162
1.60	0.227	26%	0.168
1.70	0.241	27%	0.176
1.80	0.256	28%	0.184
1.90	0.270	29%	0.192
2.00	0.284	30%	0.199
2.10	0.298	31%	0.206
2.20	0.312	32%	0.212
2.30	0.327	32%	0.222
2.40	0.341	32%	0.232
2.50	0.355	33%	0.230
2.60	0.369	33%	0.247
2.70	0.383	33%	0.257
2.80	0.398	34%	0.263
2.90	0.421	34%	0.272
3.00	0.426	34%	0.281
3.10	0.440	34%	0.290
3.20	0.454	35%	0.295
3.30	0.469	35%	0.305
3.40	0.483	35%	0.314
3.50	0.498	35%	0.323

The discount will be 35% for all gas prices above $3.50 per m.c.f.

3.2.2 If Allen uses more than the base amount (25 million pounds) of steam each year, the price of steam will be discounted at year's end according to the table below:

STEAM CONSUMPTION MILLIONS OF LBS.	STEAM PRICE PER 100 LBS.	DISCOUNT	DISCOUNTED STEAM PRICE PER 100 POUNDS
25	$ 0.085	0%	$ 0.085
30	0.085	5%	0.080
35	0.085	10%	0.077
40	0.085	15%	0.072

The discount will be 15% for all steam consumed above 40 million pounds.

3.3 The parties agree that Allen will pay to the City for such steam energy no less than the minimum sum of $20,000.00 per year, except as provided in Sections 4.5, 4.6, 4.7 and 4.8 hereinbelow in connection with the interruption of service. The parties understand that such annual payment is calculated on the basis of natural gas available to Allen at the price of sixty cents ($0.60) per m.c.f.; and therefore, agree that such payment will be increased or decreased in direct proportion to any increases or decreases in such price of natural gas available to Allen, computed on the basis of the average annual cost of such natural gas. The normal charges for such metered steam used by Allen will be billed monthly to Allen by the City, and any balance remaining due to the above referenced minimum payment will be billed annually.

3.4 Credit will be given Allen by the City for any Allen wastewater used in the energy conversion sytem.

3.5 All payments will be due from Allen to the City within ten (10) days of the billing date. The City may charge a 10% late charge on any bill not paid within said ten (10) day period; and, if such billing is not timely paid with late charge within fifteen (15) days of the billing date, the City may discontinue service upon not less than five (5) days written notice to Allen. No such discontinuation of service shall render the City liable for damages or relieve Allen from performance of its obligations hereunder; and the City reserves the right in any event, to insist upon specific performance by Allen of its obligations under this Agreement or to claim damages.

Section 4: Operation of Heat Recovery System

4.1 The City agrees to establish by lawful ordinance a Sanitation Facilities Commission, the membership of which shall consist of not more than five persons, of which at least two members shall be representatives designated by Allen. The function of this commission shall be as liaison between the City Council and the management of the waste disposal and energy conversion system.

4.2 The City agrees to contract for the operation of the plant and energy conversion system at least five days per week from 7:00 a.m. Monday through 6:00 p.m. Friday; and, further, to make steam produced by such system available for use by Allen during such specified time period at the minimum rate of 10,000 pounds of saturated steam between 100 and 150 pounds pressure per square inch (PSIG) per hour.

4.3 The City agrees to contract for proper maintenance of the heat recovery system in order to avoid any unnecessary interruption of service to Allen.

4.4 The City agrees to give Allen sufficient notice of any interruption of service required for the making of necessary repairs, installations or improvements to the system in order to afford Allen the opportunity to connect its service facilities to other sources of energy supply.

4.5 The City agrees to give Allen ninety (90) days written notice if for some reason (other than for delinquent payment) the City must discontinue service to Allen from this plant.

4.6 If proper notice is given by the City to Allen as hereinabove indicated, the City shall not be liable to Allen for damages resulting from the termination or interruption of service required for the making of necessary repairs, installations or improvements or any other reasonable cause beyond the control of the City. However, in the event of any such interruption of service, the minimum annual payment required of Allen in the amount of $20,000.00, or as adjusted, pursuant to Section 3.3 shall be reduced proportionately on the basis of the number of days of interrupted service resulting in less than two hundred forty (240) days of operation per annum.

4.7 In the event Allen's plant or the City's Waste Disposal and Energy Conversion System shall be damaged or destroyed or their operations interrupted by Act of God, fire, other acts of the elements, riots, civil disorder, war or any other cause beyond the reasonable control of Allen or the City, then in such event either party hereto shall be relieved from performance under this agreement, including payment of minimum annual energy charges by Allen, until normal operations are restored.

4.8 The City shall be responsible for performance of its obligations under this Agreement or the Lease Agreement referred to above, even though the City may have contracted with a third party for performance of all or part of its obligations. Failure by the City to fully perform its obligations under both of said agreements shall relieve Allen of its obligations hereunder also.

Section 5: Amendment of Agreement

This Agreement supersedes all prior negotiations and oral understandings, if any, and may not be amended or supplemented except by an instrument in writing signed by both parties hereto.

Section 6: Assignment

This Agreement shall be binding upon and inure to the benefit of the parties hereto and their respective successors and assigns to which this Agreement relates. Allen shall have the right to transfer its interest under this Agreement to any affiliated or successor legal entity subject to all of the terms and conditions of this Agreement.

Section 7: Effective Date

This agreement shall be in full force and effect only upon approval by written resolution duly adopted by the City Council at a regular or special meeting legally called and held.

IN WITNESS WHEREOF, the parties hereunto have caused this Agreement to be duly executed this 11th day of December, 1974.

CITY OF SILOAM SPRINGS, ARKANSAS

BY:______________________________
MAYOR

(SEAL)

ATTEST:

____

ALLEN CANNING COMPANY

BY:______________________________
PRESIDENT

(SEAL)

ATTEST:

____

APPENDIX F

ENERGY CONVERSION FORMULAS

HEAT RELEASE

Municipal Waste, "As Received"	3,000 - 6,000 Btu/Lb.
Hospital Waste, Milled and Mixed	6,000 - 9,500 Btu/Lb.
Coal	10,500 - 14,100 Btu/Lb.
#2 Oil	138,500 Btu/Gal.
Natural Gas	970 - 1,030 Btu/Cu. Ft. @ 4 oz psig Std. Measure 100,000 Btu/Therm (100 Cu. Ft.)
Propane	2,590 Btu/Cu.Ft.

DENSITIES

Municipal Waste, "As Received"	5 - 14 Lbs./Cu. Ft.
Municipal Waste, Combustible Portion	4 - 8 Lbs./Cu. Ft.
Hospital Waste, Milled and Mixed	3.5-6.5 Lbs./Cu. Ft.
Coal	40 - 44.4 Lbs./Cu. Ft.
#2 Oil	57.1 - 64.5 Lbs./Cu. Ft.
Residue, Municipal Waste	38 - 55 Lbs./Cu. Ft.

STEAM PRODUCTION

100 Lb. Steam at 100 psig requires 100,000 Btu average @ 100% Efficiency Energy Transfer.

@ 75% Transfer Efficiency requires 133,333 Btu

1 Btu = 1 lb. water raised 1°F.

= .0010306 lb. steam with feed water @ 212°F.

1 Boiler Horsepower (BHP) = 33,475.3 Btu/Hr. Heat to Steam

= 34.5 Lb. Steam evaporated per hour from 212°F.

= 44,633 Btu/Hr. Fuel Input @ 75% Transfer Efficiency

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